Agriculture and Food

AIMS Agriculture and Food, 9(4): 1064–1109.
DOI: 10.3934/agrfood.2024057
Received: 11 July 2024
Revised:12 October 2024
Accepted: 24 October 2024
Published:02 December 2024

https://www.aimspress.com/journal/agriculture

Review

The potential uses of Galangal (*Alpinia* sp.) essential oils as the sources of biologically active compounds

R. Amilia Destryana[1,4], Teti Estiasih[2,*], Sukardi[3] and Dodyk Pranowo[3]

[1] Doctoral Program of Agro-industrial Technology, Universitas Brawijaya, Malang, 65145, Indonesia
[2] Department of Food Science and Biotechnology, Universitas Brawijaya, Malang, 65145, Indonesia
[3] Department of Agro-industrial Technology, Universitas Brawijaya, Malang, 65145, Indonesia
[4] Department of Agricultural Product Technology, Universitas Wiraraja, 69415, Indonesia

* **Correspondence:** Email: teties@ub.ac.id; Tel: +62341569214.

Abstract: The uses of essential oils in food and traditional medicine have attracted researchers worldwide for applications in the food, agriculture, cosmetics, and health industries. Among the sources of essential oils, the Alpinia genus produces galangal essential oils with great potential for use in many applications. This genus has been used for a long time in traditional medicine in some countries along with for food flavouring and spices. These essential oils from many plant organs of this genus contain several bioactive compounds with the typical phytochemical is 1,8-cineole or eucalyptol. Scientifically, the bioactivity of galangal essential oils has been proven. Some efforts have been conducted efficiently to extract the galangal essential oil, including using novel technologies- This article aims to review the Alpinia species bearing essential oils and their traditional uses, phytochemicals of galangal essential oils and their bioactivity, the methods of extraction, phytochemical profiles, stabilization, uses, and potential applications of these essential oils. This review also compares the bioactivity of galangal essential oils and their traditional uses and potential applications. The results of this review show that Alpinia species has a long history to use as traditional medicines in many countries. There is a closely correlation between traditional uses of galangal with the scientifically proven of health benefits. The studies on galangal essential oil bioactivity have deeply explored the capability as antioxidants, antimicrobial, anti-inflammatory, anticancer, anti-antiparasitic activities and cardiovascular impairment. The uses of galangal essential oils are correlated with their bioactivity. Galangal essential phytochemicals is characterized by the presence of 1,8-cineole. The 1,8-cineole is found in the parts of this plant organ with its concentration varies depending on the galangal species. Some studies indicates that the novel technologies produce higher yield than conventional method for essential oil extraction. The application of galangal essential oil has the constraint of high hydrophobicity, resulting in a poor solubility in the aqueous phase. Various techniques of emulsification are used to improve the its water miscibility. Galangal essential oils are potential to use in many sectors such as agriculture, food, pharmaceutical and personal care industries. The appropriate extraction method is still a challenge mainly to improve the yield along with preserving the bioactive compounds. Another challenge is exploring other *Alpinia* species, proof their health benefits, and exploring their potential uses in many sectors.

Keywords: *Alpinia* genus; galangal essential oil biological activity; galangal essential oil; galangal essential oil extraction; galangal essential oil phytochemicals

1. Introduction

Genus of *Alpinia* or galangal is a large genus of the Zingiberaceae family, which is widely spread in many Asia tropical regions such as India, China, and Indonesia [1]. The family Zingiberaceae is widely spread across the tropics of Africa, Asia, and America consisting of about 50 genera and 1600 species. About 22 genera and 170 species are found in India, and about 150 species belongs to 23 genera are found in Malaysia Peninsula. The foremost genus of the Zingiberaceae is *Alpinia* which has been used as medicines and non-medicines for a long time [2].

Galangal is a rhizome consisting of 250 species and the most well-known is greater galangal (*Alpinia galanga* (L.) Willd.) and lesser galangal (*Alpinia officinarum* Hance) [3]. These flowering plants are native to Asia, Pacific Islands, and Australia in tropical and subtropical regions [4]. This genus has characteristics resemble to turmeric and ginger (Figure 1). Galangal rhizome is often used in culinary in many countries, especially Asia. *Alpinia* is a monocotylodenous plant that one of the major divisions of the flowering plants or angiosperms and belongs to the Zingiberaceae family. *Alpinia*, commonly known as ginger-lilies, grown for their flowers and spices [5]. The flowers are thirty centimeters long. The bracts are ovate to lanceolate in form and can be greenish, white, or red. The leaves are oblong to lanceolate, green, and have white edges [6].

Members of the Alpinia genus have aromatic and attractive inflorescences in both aerial and underground parts, which are used for essential oil extraction. These plants have bioactive compounds that can be used for health and disease therapeutics [4]. Medicinal plants are significant in discovering new medications, expanding plant drug sources, and improving functional foods. They are also effective in the food, fragrance, and cosmetics industries [7,8]. *Alpinia* rhizomes are used in cooking and traditional medicine. Galangal is frequently used in traditional way to treat a variety of ailments such as, stomach discomfort, colds, and edema [9]. The *Alpinia* genus such as greater and lesser galangal are ancient and highly revered medicinal agent in traditional medicines such as Traditional Chinese, Ayurvedic, and Thai folk medicine [10]. *Alpinia zerumbet* (Pers.) B.L.Burtt & R.M.Sm. is originating from West Asia, but distributed widely in South America, is used in folk medicine, mainly for hypertension and anxiety treatment [11]. Traditionally, *Alpinia* are commonly used for treating bronchitis, eczema, colitis, ulcers, digestive problems, cholera, as antioxidant [12], mouthwash, antibacterial [13–15], hypertensive cardiovascular [16], and slimming [6].

The use of rhizomes for aromatic and medicine has been a common practice over thousands of years to improve food flavour, colour, and aroma. Among them, the *Alpinia* genus is a potent source of essential oils. The important species of *Alpinia* for essential oils are *Alpinia galanga* (L.) Willd. [12,17], *Alpinia. officinarum* [13,18–20], *Alpinia purpurata* [21,22], *Alpinia speciosa* [23,24] or *Alpinia zerumbet* [11,16,25], and *Alpinia. conchigera* [14].

Figure 1. The example *Alpinia* species, *Alpinia galanga* (L.) Willd. (A) and *Alpinia purpurata* Vieill. K.Schum (B)) and their parts of the plants. A. 1. Whole plant; 2. Flower and fruit; 3. Fresh clean rhizome; 4. Stem and root. B. 1. Whole plant; 2. Stem and root; 3. Fresh clean rhizome.

Galangal essential oil is a secondary metabolite extracted from the genus of *Alpinia*. It can be derived from the root, rhizome, leaves, stem, seed, or the entire plant. Essential oils are complex mixtures of volatile and semi-volatile organic compounds that come from a single botanical source. This determines the specific aroma, flavor, and fragrance of the plants. Essential oil is the product obtained from a plant material, either by steam distillation, hydro distillation, mechanical processes, or innovative technological extraction methods. Major compounds found in essential oils include oxygenated monoterpenes, monoterpenes hydrocarbons, and oxygenated sesquiterpenes. Essential oils are soluble in alcohol, ether, and fixed oils, but they are insoluble in water [26–29]. Galangal essential oil has shown potential in the development of food and pharmaceutical products due to its antibacterial, antioxidant, insecticidal, and anti-inflammatory properties [19,30]. Galangal contains flavonoids, terpenoids, saponins, phenolic acids, and essential oil [31,32].

This article aims to discuss the uses and traditional health belief of galangal essential oils and their scientifically proven. This review also compared galangal essential oil phytochemical profiles among the *Alpinia* genus, including the essential oils from the different plant organs. Since the extraction method greatly affects the separated bioactive compounds, this article also discusses the methods for galangal essential oil extraction. The high volatility and difficulty to dissolve in water are the constraints of galangal essential oil applications that further required stabilization. The method of stabilization mainly by emulsification is also reviewed. The potential uses of the galangal essential oils in many applications in relation to their bioactivity is interesting to discuss. Therefore, the main goal of this review is present the potential uses of galangal essential oils as the sources of biologically active compounds for many applications.

2. Method of review

This article reviews the galangal oils, including the *Alpinia* species bearing essential oils and their traditional uses, extraction methods, chemical profile, bioactivity, stabilization, practical applications, and safety aspects. The literature searching is conducted with the keywords *Alpinia*, galangal, and galangal essential oil or *Alpinia* essential oils. The literature was limited to the essential oils excluding the galangal or *Alpinia* extracts that were not prepared by hydrodistillation or other methods to separate the essential oils. The relevant articles were obtained by using Google searching engine, from the PubMed website, and the journals or publishers subscribed by Universitas Brawijaya since 2001 to 2024 with the statistics of literature diostribution is shown in Figure 2. In this review, the narrative data was compared such as comparing the traditional uses and the scientific evidence of galangal essential oil bioactivity, chemical profile of galangal essential oils from different species, and the uses of galangal essential oils with their bioactivity.

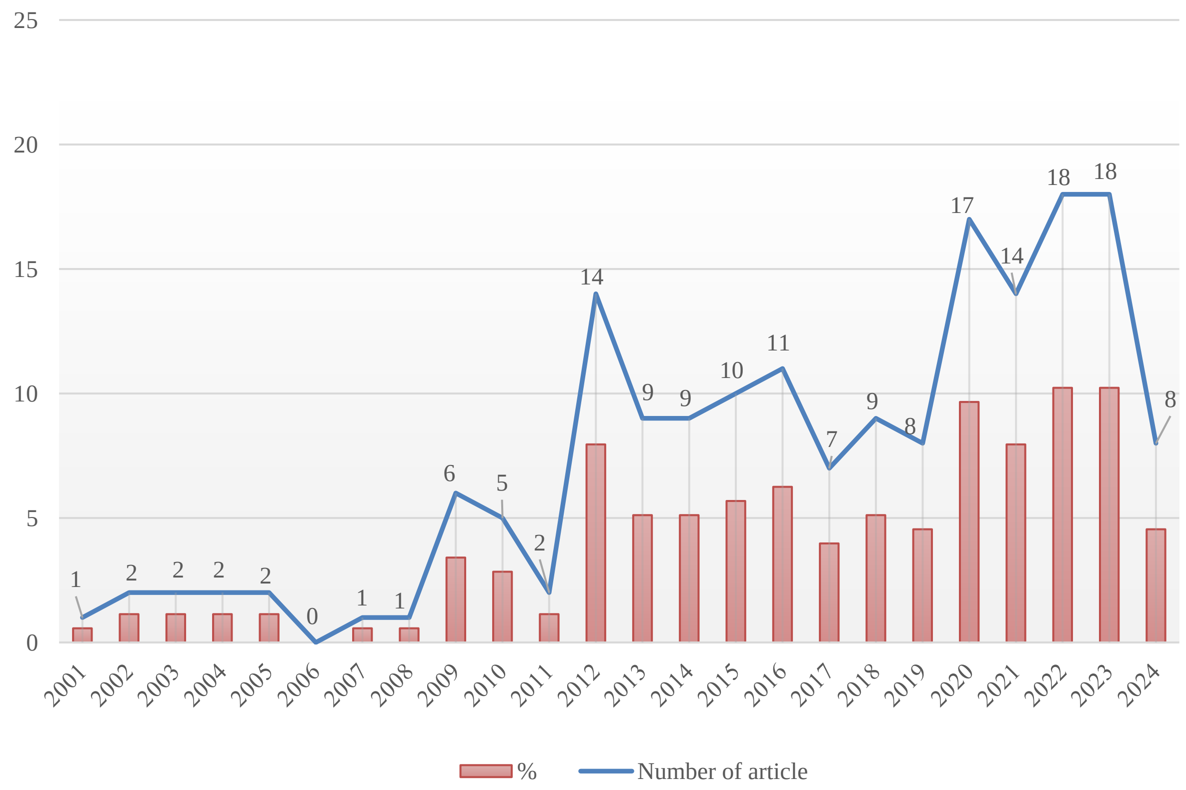

Figure 2. The statistics of used literature for galangal essential oil review.

3. Essential oil-bearing Alpinia species and their traditional uses

Alpinia species are widely distributed worldwide form their origins (Figure 3). Therefore, this genus has been used traditionally for a long time as herbs and spices, as well as traditional medicine. Galangal essential oil in *Alpinia* species might also contribute to the traditional uses of galangal species. This section discussed the traditional uses of *Alpinia* species bearing essential oils in many applications.

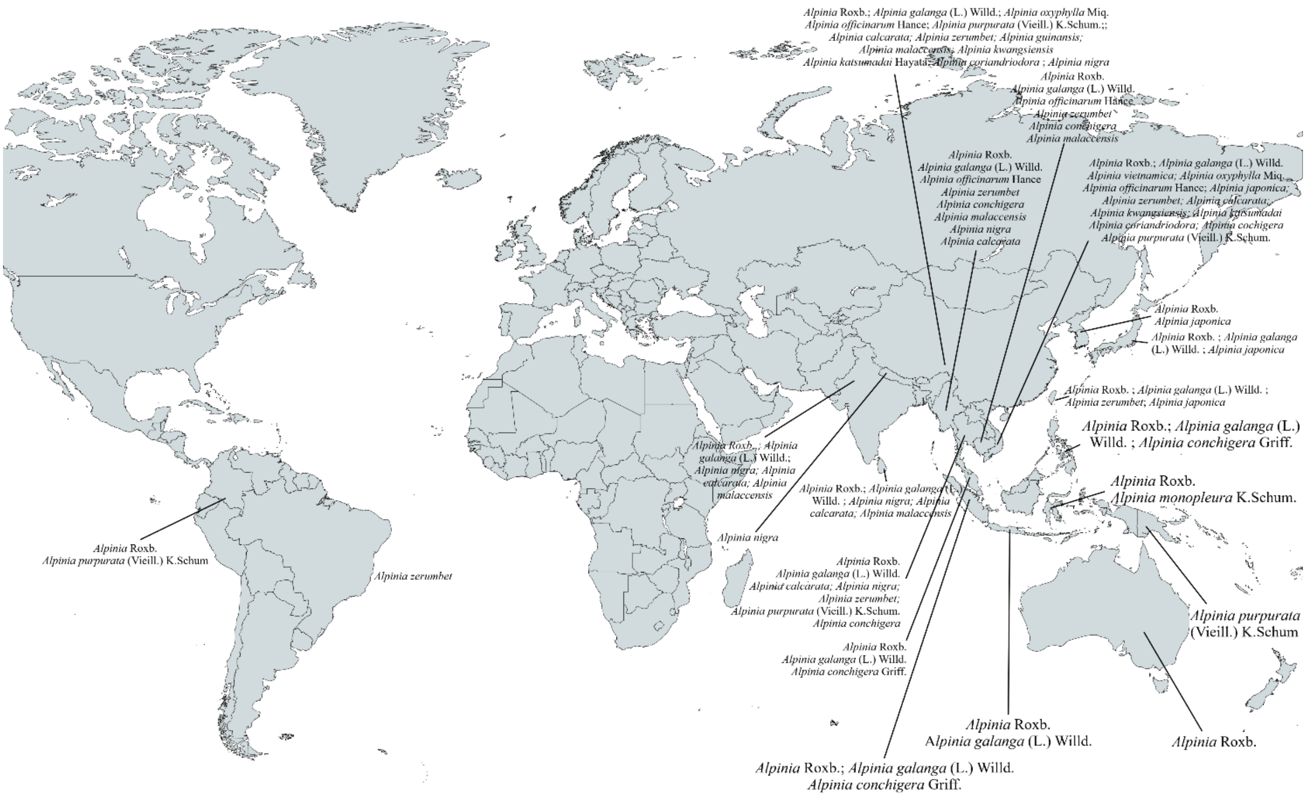

Figure 3. Geographical map of widespread distribution of *Alpinia* species.

Alpinia Roxb. is the most widespread and largest genus in the family of Zingiberaceae with 230 species spreading from the Western Ghats of India to China, Sri Lanka, Japan, Southeast Asia, Pacific, and Australia [33]. The *Alpinia* genus is the tribe of *Alpinieae* A. Rich. in the Zingiberaceae family. This tribe is evergreen herbs [33]. Morphologically, the *Alpinia* genus has rhizomes, simple wide leaves, and terminal inflorescence. All parts of this plant bear essential oils and produce aromatic compounds. This genus has a remarkably beauty of its flowers, thus widely used as ornamental plants. Various parts of *Alpinia* are used extensively for medicinal purposes including rhizomes, leaves, and flowers [34].

This genus is originated from East Asia and they are currently cultivated in many regions as ornamental and therapeutic plants [34]. *Alpinia purpurata* (Vieill.) K. Schum and *Alpinia zerumbet* (Pers.) B.L. Burtt & R.M.Sm. have a significant presence in Brazil [34]. The *Alpinia* genus is widely distributed from the most northerly species of *Alpinia japonica*, tropical regions around the world, and Australia as far south [33]. There are 51 species of *Alpinia* in China, of which 35 are endemic [35].

Genus *Alpinia* has been utilized as food, spices, and traditional medicines, in several Asian tropical regions, including Indonesia, China, and India [35]. Traditional uses of some common and well-known *Alpinia* species are very region-dependent. *Alpinia galanga* (L.) Willd. is very famous in South East Asia countries such as Indonesia, Thailand, and Malaysia. *Alpinia zerumbet* has long history to use in Ayurvedic medicinal system in India. Meanwhile, *Alpinia oxyphylla* Miq. fructus is extensively used in traditional Chinese medicine. *Alpinia officinarum, Alpinia calcarata, and Alpinia purpurata* Vieill. K.Schum are widely used in wide-ranging countries including Asia, Africa, and Latin America. The traditional uses and widespread distribution of several prominent *Alpinia* species in different parts of the world are discussed bellowed.

3.1. Alpinia galanga (L.) Willd.

Alpinia galanga (L.) Willd. is a member of Zingiberaceae family which is indigenous to Indochina, Southeast China, and commonly called greater galangal [15]. This galangal is extensively cultivated in Indonesia which is the largest supplier and producer. Greater galangal is also produced in several Asian countries such as China, India, Egypt, Malaysia, Thailand, and Sri Lanka. *Alpinia galanga* is widely used as a spice and condiment in various cuisines in Indonesia, Malaysia, and Thailand [12]. *Alpinia galanga* is extensively used in traditional medicines in most Asian countries [17].

The rhizomes of *Alpinia galanga* are used extensively in Indonesian, Thai, and Malaysian culinary, although several parts of this plant are also aromatic fragrance. The fragrance masks the undesirable smell of sea foods and a certain meat, contributing to a pleasant taste and flavour to dishes. Greater galangal is a traditional herbal crop for medicinal and food purposes. Its essential oil provides not only natural flavours, but also active ingredients for agro-products and cosmetics [36].

Besides its food and spice value, various parts of *Alpinia galanga* are used in traditional medicine for various ailment treatments such as abdominal discomfort, diarrhoea, flatulence, abnormal menstruation, stomach-ache, and inflammatory. *Alpinia galanga* rhizomes are part of Ayurvedic in India for inflammatory, rheumatism, diabetes, and neurodegenerative diseases treatments [12] also to treat microbial infections, throat infections, diabetes, cardiac diseases, ulcer, incontinence, bad breath, kidney disorders, rheumatism, bronchitis, whooping cough, chronic enteritis, and fever [17]. This plant is a key material for asthma, throat infection, inflammation, urinary ailments, and rheumatism treatments [12]. In Myanmar, the rhizomes of *Alpinia galanga* are mainly used traditionally to treat diuretics, fever, cough, stomach pain, chest pain, and indigestion [37].

3.2. Alpinia officinarum Hance

Apart from greater galangal, two closely related species (lesser galangal and light galangal) are used similarly. *Alpinia officinarum* or lesser galangal is a perennial plant (Abubakar et al., 2018) and has small rhizomes, strong smell, and taste. *A. officinarum* Hance is common planted in South Asia, China and Southeast Asia [19,20]. *Alpinia officinarum* is native to China and grows well in high humidity tropics and temperature above 15 °C. This rhizome is pungent and aromatic, and has been used as spices over 1000 years in Europe. The lesser galangal plant is commonly found in Vietnam, South East Asia, and southern China. *Alpinia officinarum* has been used traditionally for decades to treat several symptoms including pain, inflammation, stomach-ache, cold, ringworm, tooth decay, abnormal menstruation, flatulence, abdominal pain, haemorrhoids, inflammation, general weakness and others. The materials form this plant are dried, ground, and mixed with other food for treatment of general health ailments, gynaecological, and musculoskeletal disorders in several countries such Morocco, Algeria, China, Turkey, and Vietnam [2].

The decoction of boiled lesser galangal rhizome is used for stomach ache, indigestion, and malaria treatments in Vietnam. *Alpinia officinarum* is recommended for dyspepsia, flatulence, vomiting, and gastrointestinal disorders. Its powder is a quick cure for acute stomach pain. Throughout the East, this herb snuff treats the nasal infection. A mixture of *Alpinia officinarum* rhizome and lime juice is used for cough and cold. Due to aromatics, lesser galangal is used on perfumes, deodorants, room freshener in India. In Thailand, the decoction of boiled immature lesser galangal rhizomes is traditionally used to eliminate dispelling evil wind and flatulence [38].

3.3. Alpinia calcarata (Haw.) Roscoe

Alpinia calcarata (Haw.) Roscoe with common name of snap ginger, cardamon ginger, or Indian ginger, is a species of galangal which is spread in India and Malaysia [39] also Bangladesh, Sri Lanka, China, and Timor [40]. This aromatic herb is used in the traditional medicinal systems of India to treat stomach ache, fever, rheumatism, and diabetes [41,42]. Traditionally, the rhizomes of this plant are used to treat rheumatism, diabetes, inflammatory diseases, gastrointestinal problems, cough, and respiratory problems [43].

3.4. Alpinia zerumbet (Pers.) B.L.Burtt & R.M.Sm. or Alpinia speciosa (J.C.Wendl.) K. Schum

Alpinia speciosa, commonly known as light galangal, *Alpinia zerumbet,* or shell ginger, is a plant native to southeast India that grows widely in subtropical and tropical climates. It has a wider rhizome and is widely used as a substitute for greater galangal and ginger in processed food products. Its therapeutic benefits have been used in folk medicine and marketed in the food and cosmetic sectors [16]. *Alpinia speciosa* is widely found in Taiwan and is used as herbal medicine and various food preparations [44]. *Alpinia zerumbet* (Pers.) B.L.Burtt. & R.M.Sm. is a perennial ginger of the Zingiberaceae family, originated from East Asia and spread widely in tropical and subtropical regions [39]. *Alpinia zerumbet* is an aromatic plant abundant known as “colonia” in Brazil and found abundantly in north-eastern [11].

The fruit of *Alpinia zerumbet* is well known in China as “*yan-shan-jiang*”, which is used for flavouring in cuisine. Traditionally this plant is used as medicine for treating indigestion, vomiting, and diarrhoea. Its pericarps, seeds, and placenta are used widely for cardiovascular disease treatment. This plant significantly contributes to prolonged human life in Okinawa population in Japan [45]. *Alpinia zerumbet* is also used in Japanese cuisine and traditional medicines. In Brazil, its product is marketed as topical administration herbal medicine for muscular spasticity treatment. In this country, the leaves of *Alpinia zerumbet* are used as tea and infusion treatment for anxiety symptoms and arterial hypertension [25].

3.5. Alpinia purpurata (Vieill.) K.Schum.

Alpinia purpurata (Vieill.) K.Schum., with a common name as “red ginger”, is an ornamental plant with the aromatic rhizomes and leaf stalks [46]. This herb is a very popular garden plant in India [47]. This plant is used for producing dyes, spices, fibre, paper, and perfumes. This *Alpinia* is extensively cultivated on a large scale due to its durable bloom throughout the year and the durability of its inflorescences [21]. *Alpinia purpurata* is one of the medicinal plants from the family of Zingiberaceae. The flowers of *Alpinia purpurata* are boiled and the hot water infusion is used to treat cough symptoms in Venezuela. In India, its rhizomes are consumed to increase appetite, taste, and improve voice, besides for the treatments of rheumatism, sore throat, headache, and renal infection [35,46].

3.6. Alpinia oxyphylla Miq

Alpinia oxyphylla Miq. or sharp-leaf galangal is an important herb used commonly in East Asian traditional medicine such as China, Japan, and Korea. This plant is widely used for treating dyspepsia, abdominal pain, diarrhoea, 'kidney' asthenia, spermatorrhoea, and poor memory [48], intestinal disorders, inflammatory conditions, enuresis [49], urethral disorders [50], dementia, and cerebrovascular disorders [51]. Since ancient times, the fructus of *Alpinia oxyphylla* Miq. is used in medicine and food, and widely applied in traditional Chinese medicine [52] and as the one of "four famous south medicines" with aphrodisiac, tonic, and anti-polyuria effects [53].

The fruit of *Alpinia oxyphylla* is called "Yizhi" in China, and has been used for kidney, stomach, and spleen disorders for thousands of years [54]. In Hainan province, *Alpinia oxyphylla* is frequently used as healthy foods, such as preserved fruits, drinks, vegetables, and the raw material for dietary supplements [53]. Traditionally, the fructus without impurities and shells (it is called *Yi-Zhi-Ren* in China) is used to warm the spleen for stopping diarrhoea and salivation. It also warms the kidney to improve semen production and reduce urinary frequency. It also treats enuresis due to kidney disorder and diarrhoea because of spleen deficiency. This fructus reveals low side effect in long term administration [55]. *Alpinia oxyphylla* has medicinal values due to neuroprotective effect, hypnosis, and sedation, as well as improving the learning and memory ability [56].

3.7. Other Alpinia species

Alpinia guinanensis D. Fang & X. X. Chen is herbaceous perennial and endemic to the Guangxi province in China. In the southern China, it is cultivated as an ornamental plant. Traditionally, *Alpinia guinanensis* is used as a spice and folk medicine to relieve stomach ache c is a herbal plant native to Assam, India. It is a part of the Zingiberaceae family and is widely dispersed in Thailand, China, and the other Southeast Asia. *Alpinia nigra (Gaertn.) B. L. Burtt.* is used as food flavouring, vegetable diet [58] and to treat many health problems such as intestinal infection, irregular menstruation, and bone weakness. The essential oil of this species has been observed as natural preservative in the food products [59]. *Alpinia guilinensis*, an herbaceous perennial, is endemic and native to Guangxi province in China. This *Alpinia* species has been used as a food flavouring agent for fish and meat peculiar smells [60]. *Alpinia japonica* (Thunb.) Miq. is widely spread in the southeast of Japan and China. Its rhizomes are commonly used in traditional Chinese medicine for lung cold, abdominal crymodynia, rheumatism, over-strained haemoptysis, menoxenia, knocks, and falls treatments since ancient times [61].

Alpinia katsumadai Hayata (*Alpinia katsumadae* Hayata) or other name *Alpinia hainanensis* K.Schum., is widespread in the Southeast Asia [62]. *Alpinia katsumadai* is part of traditional Chinese medicine for pain, abdominal distention, and diarrhoea [63]. *Alpinia malaccensis*, with common name "Malacca ginger" or "Rankihiriya," is an important medicinal *Alpinia* genus. This plant is native to Malaysia and Indonesia but spread in wider regions including China and Northeast India. This herb is well recognized from its pharmacological values [64]. *Alpinia coriandriodora* is a perennial plant with a coriander odour and cultivated for medicinal purposes and a condiment in Guangxi province, China. This rhizome is a long-time used in Chinese medicine for treating stomach ache, indigestion, asthma, cold, and fever [65].

Alpinia conchigera Griff. is a perennial herb found in eastern and southern Bengal and southwards to Sumatera and Peninsular Malaysia. Its rhizome is used as a condiment in northern Malaysia including the young shoot as vegetable dish. Occasionally, it is traditionally used to treat fungal infections. The rhizomes are consumed for post-partum medicine in some regions of Malaysia [14]. The rhizomes of *Alpinia kwangsiensis* have been used in Chinese folk medicine for abdominal pain, cold, vomiting, stomach, and traumatic injury treatment [66].

From this section, it can be concluded that most galangal species use is for traditional medicine. These uses are as part of traditional medicine in many regions in the word such as traditional Chinese medicine in China, ayurveda in India, and *jamu* in Indonesia. Some minor application is for food preservation. This genus also contribute to the traditional food and culinary due to aromatic fragrance that might be contributed by galangal essential oils.

4. Galangal essential oil extraction methods

Extraction of bioactive compounds from galangal has been reported by conventional and non-conventional methods, among which the most widely reported is the conventional method using distillation. The different extraction method of galangal essential oil is shown in Table 1. Traditional techniques of extracting essential oil from galangal have been studied, including the use of hydro distillation and steam distillation. The novel extraction methods are including non-thermal pretreatments such as microwave-assisted extraction (MAE), ultrasound-assisted extraction (UAE), pulsed electric field (PEF), and supercritical fluid extraction (SFE). An overview of the extraction methods is shown in Figure 4.

The *Alpinia* genus are usually extracted from many parts of the plants, such as rhizome, leaves, flowers, inflorescences, pseudostems, and roots (Figure 5). Usually, drying is conducted before extraction to increase extraction efficiency. The main purpose of drying is to remove water because water will hinder the essential oil material movement form cells into the extracting solvent. Most of drying techniques apply heating to remove water, that might concomitantly also volatilize the essential oil substances. Therefore, the suitable drying technique prior to extraction is very important to determine.

Ge et al. [77] compared three drying methods of the rhizomes of *Alpinia galanga*, hot air, vacuum, and freeze drying. The results showed that hot air drying had the shortest drying time but freeze drying was the most suitable since this method could maintain rhizome microstructure and high essential oil yield. Drying methods affected the phytochemical profiles of the essential oils. Some constituents were lost during drying which was observed by the amounts of compounds before and after drying. There were 80 identified constituents before drying and only 43 compounds were detected in essential oils.

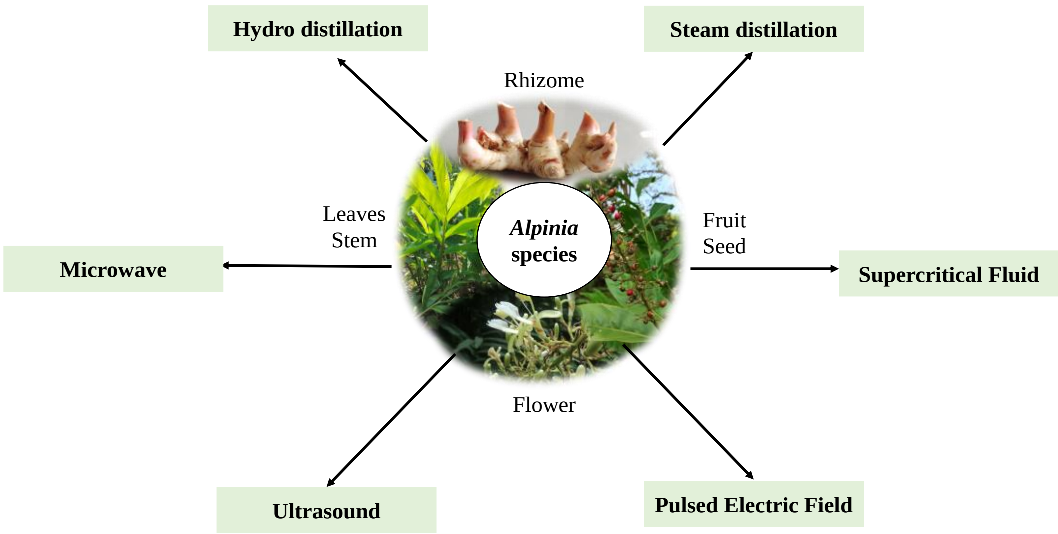

Figure 4. Overview of the extraction methods of *Alpinia* species essential oil.

Table 1. Extraction method of galangal essential oils and the yield.

Extraction Method	*Alpinia* Species and Plant Organ	Yield (%)	Ref.
Conventional			
Hydro distillation	*Alpinia galanga* (L.) Willd*;* Seed	1.8	[67]
	Alpinia galanga (L.) Willd*;* Rhizome	0.9	[67]
	Alpinia galanga (L.) Willd*;* Rhizome	0.27	[68]
	*Alpinia galanga (*L.) Willd*;* Rhizome	0.93	[69]
	Alpinia galanga (L.) Willd*;* Rhizome	0.11	[70]
	Alpinia galanga (L.) Willd*;* Rhizome	0.31	[71]
	Alpinia calcarata; Rhizome	0.48	[69]
Steam distillation	*Alpinia officinarum* (Hance) Farw*;* Rhizome	0.14	[72]
	Alpinia *officinarum*; Rhizome	7.5	[73]
Novel technology			
Microwave assisted extraction	*Alpinia officinarum;* Rhizome	0.33	[74]
Ultrasound assisted extraction	*Alpinia officinarum*; Rhizome	5.01	[75]
Pulsed electrical field assisted extraction	*Alpinia purpurat,* K.Scumm; Rhizome	0.34	[76]
Supercritical fluid extraction	*Alpinia officinarum*; Rhizome	16.3	[62]
	Alpinia officinarum Hance; Rhizome	11.1	[18]

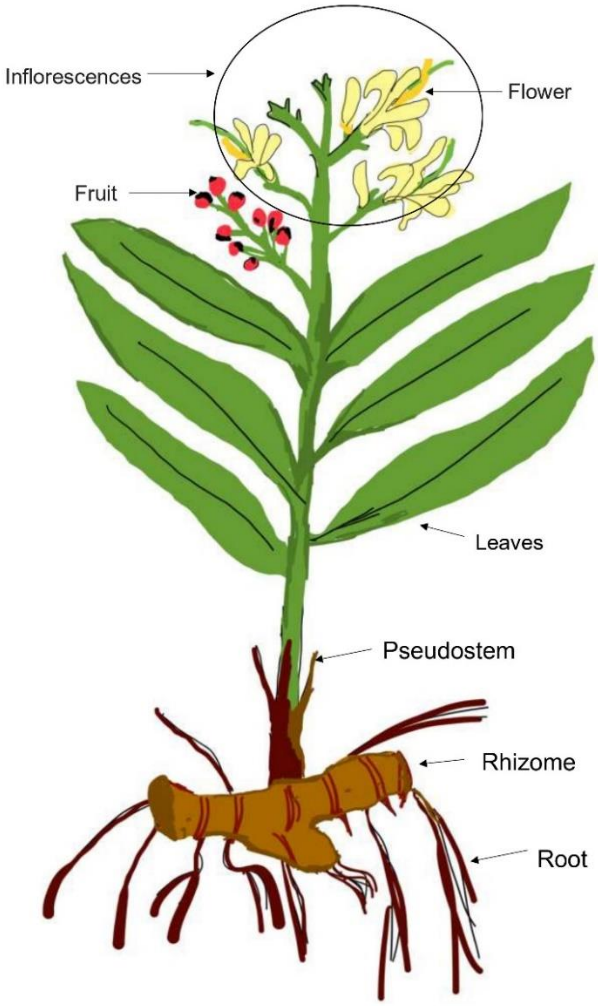

Figure 5. Schematic of *Alpinia* plant parts for essential oil extraction (rhizome, leaves, flowers, inflorescences, pseudostems, and roots).

4.1. Pretreatment

Principally, extraction is to separate the intended materials from the undesirable residues. Disrupting the cell structure of plant organ-bearing essential oils will make the leaching out of the essential oil into the extracting solvent be easier. The essential oils are localized in the organ-bearing essential oils of plant cells. Dhifi et al. [27] explained that essential oils are in the cytoplasm of certain cell secretions in one or more plant organs such as trichomes or the secretory hairs, internal secretory cells, epidermal cells, and the secretory pockets.

Kawai et al. [78] developed the method of pretreatment prior to essential oil extraction from the leaves of *Alpinia zerumbet*. Applying underwater shockwave pretreatment increased essential oil yield. The chopped dried leaves were placed in the vessel in the water and subjected to the three-cycled high pressure. This pretreatment induced multiple crack formation in the cell walls, thus creating a permeation channel to improve water vapor transport, which greatly increased the essential oil yield. This pretreatment also enhanced the antioxidant activity of the essential oil.

4.2. Conventional techniques

Hydro distillation is one of most extraction methods used to extract the essential oils. Hydro distillation is commonly used to extract essential oil from many plants and organs. In this method, the ground or chopped plant organ bearing essential oil either dried or fresh is mixed with water. The mixture is heating and the vapour is condensed to have the distilled essential oils. This method has been long-time applied widely on the rhizomes, leaves, stems, flowers, inflorescences of many *Alpinia* species. However, the lack of this method is high energy consumption, time-consuming, and low efficiency [74].

Another method of conventional technique is steam-distillation. In this method, the plant organs are heated and the vapour is condensed to have distilled essential oils. Compared to the hydro distillation, no water is mixed in steam distillation thereby lower heat transfer thus the extraction efficiency is lower. In both conventional methods, cell disruption before extraction is only by grinding or chopping. Cell destruction is very important to ease the leaching of essential is from the cell organs.

4.3. Novel technologies

Novel technologies are used to overcome the disadvantages of conventional methods in essential oil extraction [75]. The main purpose of using a novel method is to disrupt plant cells thereby the essential oils are easier to leach out into the extracting solvents. Another advantage of novel technologies is local overheating control thus avoiding phytochemical degradation. Usually, novel technologies are applied as pre-treatment before conventional extraction. Sethunga et al. [79] revealed that the combinations of novel technologies such as ultrasound assisted, enzyme assisted, microwave assisted, and supercritical fluid extraction with conventional methods increased the effectiveness and efficiency in essential oil extraction.

The studies on the novel technology extraction or pre-treatment in galangal essential oil extraction are still limited. Nguyen et al. [80] applied microwave pre-treatment in essential oil extraction from lesser galangal (*Alpinia officinarum*) and this technique successfully increased the yield. Yuan et al. [65] increased the yield of *Alpinia officinarum* Hance essential oil by developed supercritical fluid extraction (SFE). Pulsed electrical field pre-treatment before hydro distillation was used to extract the essential oil from *Alpinia purpurata*. This pretreatment increased the yields depending the voltage [76]. For spices similar to *Alpinia*, such as *Kaempferia galangal*, turbo distillation is used. In this method, the mixture is continuously stirred with a stainless steel stirrer. This process is suitable for coarse raw materials and hard-to-extract substances like spices and woods [81].

The studies comparing the novel extraction and conventional methods in one research are still limited. Table 1 shows different researchers with different *Alpinia* species. Therefore, it is rather difficult to conclude which technique is more efficient for the similar *Alpinia* species and its part. Table 1 indicates that the novel technologies produce higher yield than conventional method for *Alpinia officinarum* essential oil extraction, although the methods were used separately in different studies. Numerous studies have compared novel and traditional methods for extracting essential oils, focusing on extraction yield, time, and chemical composition. Pre-treatment prior to extraction resulted in a better extraction efficiency. A suitable, affordable, efficient, and simple method of galangal essential oils is still a challenge.

5. Chemical profile of galangal essential oils

Essential oils are aromatic and volatile liquids extracted from plant materials by distillation. Essential oils can be the mixtures of fragrant substances or a mix of fragrant and odourless substances. The fragrant substances are chemically pure compounds and volatile at ambient temperature. The characteristics of essential oils are very varied not only due to genetics, but also rainfall, climate, or geographic origin. Extraction by distillation produces essential oils which principally comprise of lipophilic and very volatile secondary metabolites. Non-volatile compounds are usually extracted by non-distillation methods [82].

The appeal of medicinal and aromatic plants is on the rise as consumers seek them for food, medicinal, and cosmetics or other uses. Essential oils are produced by diverse specialized structures, each with varying numbers and characteristics. It is important to understand the chemical and biological properties of essential oils for their potential applications in various fields. With greater awareness about food, health, and nutrition, consumers are also recognizing the advantages and potential applications of these plants and their metabolites.

There are about 2000 species from nearly 60 botanical families of plants contain essential oils. Parts of plants which bearing essential oils might be vary, including flowers (such as rose, chamomile, lavender), leaves (examples: basil, lemongrass, rosemary, peppermint), fruits such as nutmeg, peels (examples: lemon, orange, citrus), seeds such as cardamon, bark (example: cinnamon), roots and rhizomes such as ginger and turmeric [83].

Essential oils consist of organic volatile compounds, commonly whose molecular weight is lower than 300 Da. Usually, they are found partially in the vapor state at room temperature. The organic volatile compounds belong to some chemical classes including aldehydes, ethers or oxides, alcohols, ketones, amines, esters, phenols, heterocycles, amides, and mainly the terpenes. Aldehydes, alcohols, and ketones are responsible for aromatic notes of essential oils [27].

The *Alpinia* genus is aromatic herbs which have many parts containing essential oils such as rhizomes, fruits, seeds, roots, leaves, stems, shoots, pseudo stems, flowers, inflorescences, petals, and seeds. Galangal essential oils contain major compounds comprising of monoterpene hydrocarbons, oxygenated monoterpenes, and oxygenated sesquiterpenes [84]. Liang et al. [85] summarized that the main chemical component of galangal essential oil is terpenoids and its oxygenated derivatives, e.g., aldehydes, alcohols, esters, and ketones, which have a broad spectrum of anti-inflammatory, antibacterial, and antioxidant activities. Table 2 shows phytochemicals of galangal essential oils from different parts of its some species.

The 1,8-cineole or eucalyptol is almost found in all galangal essential oils and the parts of this *Alpinia* genus plant organ, but its concentration varies depending on the galangal species. Hoch et al. [86] reviewed the advantages clinical evidence of eucalyptol including respiratory disorders such as asthma, bronchitis, chronic obstructive pulmonary disease, and rhinosinusitis. This compound also has potential therapeutic applications in various conditions, such as epilepsy, depression, diarrhoea, peptic ulcer disease, diabetes mellitus, and cardiac-related heart diseases.

Table 2. The major constituents of galangal essential oil.

Alpinia species	Part of the plant	Origin	Main constituents	Ref.
Alpinia conchigera Griff.	Dried leaves, pseudostems and rhizome	Malaysia	1,8-cineole, β-bisabolene, β-caryophyllene, β-elemene, β-pinene, β-sesquiphellandrene, chavicol,	[14]
Alpinia galanga	Leaves and rhizome	India	1,8-cineole, α-terpineol, β-caryophyllene, β-pinene, borneol, camphor, fenchyl acetate, methyl cinnamate	[17]
	Leaves and stem	India	1,8-cineole, β-pinene, camphor, methyl cinnamate	[87]
	Root	India	1,8-cineole, afenchyl acetate,	[87]
	Seed	Malaysia	*(E,E)*-farnesyl acetate	[29,67]
	Whole plant	Vietnam	1,8- cineole, borneol, limonene, geranial, geranyllinelol, neral	[29]
		India	1,8-cineole, β-farnesene, β-sesquiphellandrene	[87]
	Rhizome	India	1,8- cineole, α-fenchyl acetate, α-terpineol, β-caryophyllene, β-sesquiphellandrene, camphor, chavibetol acetate, chavicol, eugenol acetate, geranyl acetate, germacrene	[68,69,87–89]
		Thailand	1,8-cineole, 4-allylphenyl acetate, α-pinene, α-terpipene, α-terpineol, β-myrcene, β-pinene, terpinen-4-ol	[70]
		Alabama, US	β-ocimene, β-myrcene, β-pinene	[90]
		Thailand	1,8-cineole, α-bisabolene, chavicol	[91,92]
		Indonesia	1,8-cineole, 4-allylphenyl acetate, α-farnesene	[93]
		China	1,8-cineole, α-pinene, β-pinene	[94]
		Sri Lanka	ρ-cymene, camphene, zerumbone	[95]
Alpinia purpurata (Vieill.) K.Schum	Inflorescences	Brazil	7-epi-alpha-selinene, α-pinene, β-pinene, trans- caryophyllene, camphene	[21]
	Inflorescences	Brazil	α-pinene, β-caryophyllene, β -pinene	[22]
	Rhizome	Indonesia	camphor, cineol, eugenol, galangin, and methyl-cinnamate	[96]
	Rhizome	Indonesia	1,8-cineole, α-pinene, α-terpineol, α-terpinene, β-myrcene, β-pinene, γ-elemene, γ-terpinene, carveol, chavicol, terpinene-4-ol, trans-carveol	[97]

Continued on the next page

Alpinia species	Part of the plant	Origin	Main constituents	Ref.
Alpinia officinarum Hance	Rhizome	China	1,8-cineole, α-bergamotene, α-farnesene, α-terpineol, γ-cadinene, globulol	[20,98]
		Gaozhou, China	α-bergamotene, linalool, trans-β-farnesene	[20,98]
		Xuwen, China	α-farnesene, δ-cadinene, γ-cadinene	[20,98]
		Impal, India	1,8-cineole, α-fenchyl acetate, β-pinene,	[68]
		China	1,8-cineole, 4-terpineol, α-pinene, α-terpineol, β-pinene	[72]
		Thailand	α-bisabolene, α-trans-bergamotene, β-sesquiphellandrene	[92]
		Hainan Island	1,8-cineole, piperitol, trans-carveol	[99]
		Vietnam	1,8-cineole, β-caryophyllene	[100]
Alpinia calcarata (Haw.) Roscoe	Rhizome and leaves	Sri Lanka	1,8-cineole, α-terpineol	[101]
	Rhizome	India	1,8-cineole, β-fenchyl acetate	[102]
	Rhizome	Bhubaneswar, India	1,8-cineole, α-fenchyl acetate, camphene,	[103]
	Rhizome	Bangalore, India	1,8-cineole, α-fenchyl acetate, geraniol	[103]
	Leaves	India	1,8-cineole, β-pinene, camphene, camphor	[103]
	Leaves	India	1,8-cineole, α-myrcene, camphor	[104]
	Whole plant	India	1,8-cineole, α-fenchyl acetate	[104]
Alpinia speciosa (J.C.Wendl.) K.Schum	Leaves	nd	1,8-cineole , ρ-cymene	[23]
	Fresh leaves, flower	Brazil	1,8-cineole, ρ-cymene, γ-terpinene	[24]
	Fresh stems, leaves, flowers and fruits	Japan and Brazil	1,8-cineole, borneol, camphene, camphor, linalool	[29]
	Fresh leaves	Japan	1,8-cineole, α-pinene, α-phellandrene, β-phellandrene, β-pinene, ρ-cymene, camphene, champor, limonene, myrcene	[78]
	Stems, leaves, flowers and fruits	China	1,8-cineole, borneol, camphene, camphor, linalool	[105]

Continued on the next page

Alpinia species	Part of the plant	Origin	Main constituents	Ref.
	Rhizome	India	1,8-cineole, 4-terpineol, β-pinene, o-cymene, γ-terpinene, fenchyl acetate	[106]
Alpinia guinanensis	Fresh leaves	China	1,8-cineole, α-phellandrene, β-pinene	[57]
Alpinia nigra	Dried leaves, flower, seed, rhizome	India	α- humulene, α-pinene, β-pinene, β-caryophyllene, caryophyllene oxide	[59]
Alpinia oxyphylla Miq	Fruit	China	Nootkatone, valencene	[50]
	Whole plant	China	(-)-Spathulenol, β-Guaiene, o-Cymene, caryophyllene oxide, nootkatone,	[107]
Alpinia guilinensis	Fruit	China	1,8-cineole, β-phellandrene, β-pinene	[60]
	Leaves	China	α-pinene, β-pinene, β-phellandrene	[60]
	Stem	China	α-pinene, β-pinene, β phellandrene	[60]
Alpinia coriandriodora	Rhizome	China	*(E)* -2-decenal, *(E)*-2-decenyl acetate, *(Z)*-3-dodecenyl acetate, *(E)*-2-octenal, trans-2-decenoic acid	[65]
Alpinia hongiaoensis	Leaves	Vietnam	β-pinene, β-selinene, aristolochene, methyl trans-cinnamate, valencene	[108]
	Rhizome	Vietnam	α-pinene, β-pinene, camphene, limonene, methyl trans-cinnamate	[108]
Alpinia kwangsiensis	Rhizome	China	α-pinene, β-pinene, camphor, eucalyptol	[109]
Alpinia monopleura	Leaves	Indonesia	α-caryophyllene, α-pinene, caryophyllene oxide, β-pinene, β-caryophyllene, limonene	[110]
	Fruit	Indonesia	α-caryophyllen, α-pinene, β-caryophyllene, β-pinene, caryophyllene oxide, limonene	[110]
Alpinia vietnamica	Leaves	Vietnam	1,8-cineole, α-pinene, α-terpineol, geraniol, limonene, linalool, myrcene	[111]
	Rhizome	Vietnam	1,8-cineole, α-pinene, β-pinene, geraniol	[111]
Alpinia rafflesiana	Fresh fruits	Malaysia	1,8-cineole, caryophyllene oxide, tetracosane	[112]
	Pseudostems	Malaysia	1,8-cineole, myrcene, trans-caryophyllene	[112]
	Leaves	Malaysia	(*2E*, *6Z*)-farnesol, caryophyllene oxide, trans-caryophyllene	[112]
	Rhizome	Malaysia	α-terpineol, Ƭ-cadinol, tetracosane	[112]

*nd= no data.

5.1. Alpinia galanga (L.) Willd.

Essential oil of *Alpinia galanga* revealed fifty-six volatile compounds and the most dominant was oxygenated monoterpenoids. The 1,8-cineole was the major oxygenated monoterpenoid compound in this essential oil and its quantity was higher in essential oil from *Alpinia galanga* than that from *Alpinia calcarata*. The 1,8-cineole is an important aroma compounds used widely in pharmaceutical industry for antiseptic, expectorant, and anaesthetic. The aroma compounds in *Alpinia galanga* essential oil were α-pinene, α-terpineol, chavicol, methyl eugenol, ß-farnesene, eugenol, and ß-sesquiphellandrene [113].

Zhou et al. [114] reported the major components of *Alpinia galanga* rhizome essential oil comprised of methyl cinnamate, ethyl cinnamate, and n-pentadecane. Moreover, nine main compounds presented in greater galangal rhizome essential oil, identified as ethyl cinnamate, methyl cinnamate, a-fenchyl acetate, n-pentadecane, 1,8-cineole, 3-carene, (-)-camphene, isobornyl acetate, 18-crown-6, (-)-borneol. Previously, Mallavarapu et al. [115] identified the main compounds in essential oil from the rhizome of greater galangal, comprising of 1,8-cineole, α-fenchyl acetate, α-terpineol, *(E)*-methyl cinnamate, and camphor. The report of Raina et al. [68] showed the compounds in essential oils of greater galangal rhizome consisted of 1,8-cineole, α-terpineol, terpinen-4-ol, and α-pinene as the major constituents. The study of Zhou et al. [105] identified methyl cinnamate, ethyl cinnamate, n-pentadecane, and 1,8-cineole.

The major volatile substances from *Alpinia galanga* flowers were dimethyl trisulfide, dimethyl pyrazine, mercaptomethylbutanol, α-humulane, β-elemene, pentadecane, β-guaiene, pentadecane, humulene oxide, bulnesol, α-bisabolol, and β-farnesol [116]. Furthermore, Tian et al. [117] reported the composition of essential oil from the flower of *Alpinia galanga*, comprising of mainly farnesene, and followed by farnesyl acetate, aceteugenol, eugenol, E-nerolidol, decyl acetate, octyl acetate, sesquirosefuran, *(E)*-farnesene, and germacrene D. It could be concluded that not all of the volatile compounds are the constituents of essential oils of the flower of *Alpinia galanga*.

Sahoo et al. [17] studied the effect of cultivation method, *in vitro* propagated, and conventionally propagated plants, on the essential oil composition of *Alpinia galanga* rhizome essential oils. This study revealed that there were no differences of essential oil composition from the leaves, comprising of β-pinene, eucalyptol, methyl eugenol, camphor, and borneol as the common compounds. Similarly, the rhizomes from both propagated plants contained essential oil with common principal components including eucalyptol, camphor, β-pinene, fenchylacetate, and α-terpineol. The 1,8-cineole or eucalyptol was found as the main compound of rhizome and leaf essential oil of *Alpinia galanga*.

5.2. Alpinia zerumbet (Pers.) B.L.Burtt & R.M.Sm./Alpinia speciosa (J.C.Wendl.) K. Schum

The profiling of the leaf essential oil of *Alpinia zerumbet* revealed a wide variety of compounds, including 1,8-cineole and terpinen-4-ol. Both compounds are able to inhibit microbial growth [25]. Previously, Feng et al. [118] identified the phytochemicals of essential oils from stems, flowers, leaves, and fruits of *Alpinia zerumbet*. All organs were dominated by the classes of oxygenated mono terpenes and monoterpene hydrocarbons. Each organ produced different essential oils yield, ranging from 0.13% to 0.62%. The highest yield was from the fruits and the lowest was from the stems, meanwhile, flowers and leaves produced considerably low yield. There were 45 identified compounds in the essential oils with the common major constituents were camphene, eucalyptol, linalool, camphor, and borneol. The compound of m-cymene was present quite abundant in essential oils from flowers, stems, and fruits, but *o*-cymene was predominant in that of leaves.

The study of Pereira et al. [23] showed that the essential oils form the leaves of *Alpinia speciosa* contained 1,8-cineole, camphor, and sabinene as major compounds. According to Indrayan et al. (2010), the essential oils from the rhizomes of *Alpinia speciosa* is rich in antimicrobial bioactive compounds, such as monoterpenoid hydrocarbons (y-terpinene, sabinene, β-caryophyllene and p-cymene), oxygenated monoterpenes (1,8-cineole, terpinene-4-ol).

5.3. Alpinia officinarum Hance

Alpinia officinarum rhizomes contained various important bioactive compounds including essential oils, diarylheptanoids, flavonoids, glycosides, and phenylpropanoids [119,120]. Zhang et al. [20] identified and profiled *Alpinia officinarum* rhizome essential oils by GC MS from 10 localities in China. The yield of essential oils ranged from 0.93% to 4.35%. that was affected by localities. Totally 53 compounds were identified with the predominant compounds consisted of 1,8-cineole, α-farnesene, γ-cadinene, α-terpineol, α-bergamotene, and globulol. The quantity of each compound also varied depending on the habitats. *Alpinia officinarum* rhizome essential oil is characterized by 1,8-cineole (eucalyptol), which is also the determinant of this herbal quality. The Chinese Pharmacopoeia has also recommended the content of 1,8-cineole in dried of this rhizome should be not less than 0.15 wt%. Reid et al. [121] reported minor compounds of *Alpinia officinarum* essential oil which is consisted of carotol, fenchylacetate, α-eudesmol, camphene, *(E)*-methylcinnamate, and borneo. The 1,8-cineole exhibits various biological activities such as anti-inflammatory [122], anti-oxidant [86], bronchodilatory, mucolytic or secretolytic, and antimicrobial [123,124].

5.4. Alpinia calcarata (Haw.) Roscoe

Alpinia calcarata possess antioxidant, antimicrobial, antinociceptive, gastroprotective, anti-inflammatory, and antidiabetic activities [102]. Profiling of *Alpinia calcarata* revealed fifty-six volatile compounds in essential oil of which the most dominant was oxygenated monoterpenoids. The major constituent in oxygenated monoterpenoid was 1,8-cineole. *Alpinia calcarata* substantially contained high α-fenchyl acetate, camphor, camphene, α-terpineol, borneol, and *(E)*-methyl cinnamate [125]. Erusappan et al. [43] summarized that the major constituents of essential oils the rhizomes of *Alpinia calcarata* were α- and β fenchyl acetates, cubenol, α-terpineol, terpinen-4-ol, 1,8-cineole, and camphor, whereas from the leaves consisted of a-terpineol, 1,8-cineole, borneol, α-myrcene, and camphor.

5.5. Alpinia purpurata (Vieill.) K.Schum

The essential oil from *Alpinia purpurata* inflorescence contained 30 volatile constituents (mainly mono- and sesquiterpenes). The main compounds found in the oil were α-pinene, β-pinene, camphene, 7-epi-α-selinene, and trans-caryophyllene [21]. Santos et al. [126] evaluated the essential oils obtained by hydrodistillation from the flowers of *Alpinia purpurata* with red and pink variants. GC/MS analyses identified 42 compounds with α-pinene, β-pinene, and β-caryophyllene as the major components.

The plant origin affects the constituents of red ginger's essential oils. Also, different parts of plant reveal different essential oil composition. Leaves, rhizomes, and flowers have 62, 52, and 47 compounds. The rhizome essential oil of *Alpinia purpurata* from Fiji contained α- and β-pinene, while the flower and leaf essential oils contained the major constituents of α-pinene, β-pinene, and β-caryophyllene. The major constituents of *Alpinia purpurata* leaf essential oil from Amazon were 1,8-cineole, β-pinene, and *(E)*-methyl cinnamate. The flower essential oils were dominated by β- and α-pinene. The leaf essential oil of *Alpinia purpurata* from Rio Brazil was dominated by β-pinene and α-pinene. The main compounds of *Alpinia purpurata* rhizome essential oil from Indonesia were 1.8-cineole, β-caryophyllene, chavicol, and α-selinene. The essential oils from *Alpinia purpurata* flowers of pink and red cultivars revealed 42 compounds, with the major components were α-pinene, β-pinene, and β-caryophyllene [127].

5.6. Alpinia conchigera Griff.

The hydro-distilled essential oils from the dried leaves, rhizomes, and pseudostems of *Alpinia conchigera* Griff. (KL 5049) consisted of 40, 39, and 33 constituents, respectively. The classes of identified compounds are monoterpene, sesquiterpene, esters, aldehydes, phenols, and hydrocarbons, with the quantity of the compounds in each class being different for each part of plant organ. The essential oil from the leaves comprised of 18 monoterpenes, 15 sesquiterpenes, three esters, two aldehydes, one hydrocarbon, and one phenol. As many as 15 monoterpenes, 11 sesquiterpenes, three esters, two aldehydes, one phenol, and one hydrocarbon were found in the essential oil from the pseudostem. The rhizome essential oil had 17 monoterpenes, 15 sesquiterpenes, three esters, two aldehydes, one hydrocarbon, and one phenol [14].

The most abundant compounds in the leaf essential oil were β-bisabolene, β-pinene, β-sesquiphellandrene, chavicol, and β-elemene. Meanwhile, the pseudostem essential oils were dominated by β-bisabolene, β-sesquiphellandrene, β-caryophyllene, and β-elemene. In the rhizome essential oils, 1,8-cineole, β-bisabolene, β-sesquiphellandrene, and β-elemene were the predominant components. All essential oils exhibited antifungal and antibacterial activity [14].

Van et al. [84] compared the composition of essential oils from 6 Zingiberaceae species, including *Alpinia conchigera*. There was a similarity between the four species. The principal constituents of the essential oils isolated from four species, *Alpinia conchigera, Curcuma pierreana, Stahlianthus campanulatus*, and *Zingiber zerumbet*, comprising of camphene, α-copaene, p-xylene, and α-santalene.

5.7. Alpinia nigra

The essential oils obtained by hydro-distillation from the different parts of *Alpinia nigra*, seeds, flowers, leaves and rhizomes, have transparent oil from seeds and flowers, yellowish oil from leaves, and reddish brown from rhizomes with a specific odour. The yields were 0.18%, 0.76%, 0.23%, and 0.06% for rhizomes, flowers, seeds, and leaves, respectively. Principal constituents in *Alpinia nigra* essential oils are β-caryophyllene, β-pinene, α humulene, α-pinene, caryophyllene oxide, and *(E)*-nerolidol [59]. Whereas, Kanjilal and Kotoky [128] revealed that the rhizomes and leaves of *Alpinia nigra* were aromatic indicating the occurrence of essential oils. The major constituent of the essential oils from leaves and flowers of this plant was 1,8-cineole and other compounds comprised of camphor, β-pinene, α-pinene, carotol, α-fenchyl acetate, α-terpineol, and camphene as the minor constituents.

5.8. *Alpinia guilinensis*

The identified compounds in the essential oil from fruit, leaves, and stem of *Alpinia guilinensis* obtained by hydro-distillation were almost the same, with the variability in minor constituents. Fruit essential oils had 14 compounds with the major components in decreasing concentration order were β-phellandrene, 1,8-cineole, β-pinene, methyl cinnamate, and α-pinene. The leaves essential oil revealed 15 compounds with the most predominant were β-pinene, α-pinene, and β-phellandrene. In the stems essential oil, 18 components were identified, with the most dominant components being β-pinene, β phellandrene, and α-pinene. The similar major compounds among essential oils from three different parts of *Alpinia guilinensis* were β-pinene, α-pinene and β-phellandrene. The 1,8-cineole was abundantly found in essential oil from fruits, but the quantity is quite low in that from leaves and stem. Fruit essential oils contained more compounds, and the only found in this plant organ were humulene, methyl cinnamate, caryophyllene oxide, and nerolidol. Caryophyllene was only identified in leaves essential oil, meanwhile, terpinolene, (+)-4-carene, and δ-cadinene were the compound only found in the essential oil from this *Alpinia* species [60].

5.9. *Alpinia coriandriodora*

GC-FID/MS analysis showed that the major chemical constituents of essential oil from the rhizomes of *Alpinia coroandriodora* were *(E)*-2- octenal, *(E)*-2-decenal, *(E)*-2-decenyl acetate, *(Z)*-3-dodecenyl acetate, and trans-2-decenoic acid [65].

5.10. *Other Alpinia species*

Xie et al. [50] isolated a compound from the essential oil the fruit of *Alpinia oxyphylla* which was valencene and nootkatone. This compound is a flavouring for foods and tobacco with insecticidal against *Drosophila melanogaster*. The main components of the essential oils from the rhizomes and leaves of *Alpinia hongiaoensis* were β-pinene, aristolochene, methyl *trans*-cinnamate, β-selinene, and valencene [108]. Hydro-distilled extracted essential oil from the rhizomes of *Alpinia kwangsiensis* revealed 31 compounds with the main compounds comprising of camphor, eucalyptol, β-pinene, and α-pinene [44]. The major constituents of *Alpinia monopleiura*, an endemic and widespread galangal in Sulawesi, Indonesia, are α-pinene, β-caryophyllene, β-pinene, α caryophyllene, limonene, and caryophyllene [110]. Tra et al. [111] reported the major compounds of the essential oils from rhizomes and leaves of *Alpinia vietnamica* were classified into monoterpene hydrocarbon and oxygenated monoterpene, consisting of 1,8-cineole, β-pinene, geraniol, and α-pinene. Jusoh et al. [112] reported the main constituents of rhizome and leaves of *Alpinia rafflesiana*. The essential oil from the leaves of this *Alpinia* species comprised of trans-caryophyllene, caryophyllene oxide, *(2E,6Z)*-farnesol, and α-terpineol, while 1,8-cineole, myrcene, α-terpineol, and trans-caryophyllene were the major components in the pseudostem essential oil. The rhizome essential oil constituted mainly of tetracosane, τ-cadinol, α-terpineol, whereas tetracosane, (2E,6E)-farnesol, α-terpineol, and caryophyllene oxide were the major constituents in the fruit essential oil.

Table 3. Typical phytochemicals of galangal essential oils from different parts of different *Alpinia* species.

Plant organ	Typical phytochemicals	*Alpinia* species	Ref.
Rhizomes		*Alpinia galanga*	[68–70,87–89,91–94];
	1,8-cineole	*Alpinia purpurata* Vieill. K.Schum	[97]
	1,8-cineole	*Alpinia officinarum* Hance	[20,68,72,98–100]
	1,8-cineole	*Alpinia calcarata* (Haw.) Roscoe	[101]
	4-terpineol, 1,8-cineole	*Alpinia speciosa* (J.C.Wendl.) K. Schum	[106]
Root	afenchyl acetate and 1,8-cineole	*Alpinia galanga*	[87]
Leaves	1,8-cineole, β-pinene, camphor	*Alpinia galanga*	[87]
	1,8-cineole, camphor	*Alpinia calcarata* (Haw.) Roscoe	[104]
	1,8-cineole , ρ-cymene	*Alpinia speciosa* (J.C.Wendl.) K. Schum	[23]
	1,8-cineole, α-phellandrene, β-pinene	*A. guinanensis*	[57]
	β-pinene, β-caryophyllene	*A. nigra*	[59]
	1,8-cineole, β-pinene, β-caryophyllene	*Alpinia conchigera Griff.*	[14]
Flower	1,8-cineole, camphene, linalool, camphor, borneol	*Alpinia speciosa* (J.C.Wendl.) K. Schum	[105]
Inflorescences	α-pinene, β -pinene and β-caryophyllene	*Alpinia purpurata* Vieill. K.Schum	[21,126]
Seed	(e,e)-farnesyl acetate	*Alpinia galanga*	[29,67]
Fruit	camphene, 1,8-cineole, linalool, camphor, borneol	*Alpinia speciosa* (J.C.Wendl.) K. Schum	[105]
	nootkatone, β-guaiene, o-cymene, caryophyllene oxide	*Alpinia oxyphylla Miq*	[107]

Based on the data in Table 2, it is concluded that some similar compounds are found in essential oils from different parts of different *Alpinia* species. These compounds are summarized in Table 3. 1,8-cineole is a typical phytochemical of galangal essential oils from rhizomes. This compound is found in the rhizome of all *Alpinia* species. Meanwhile, almost essential oils from different *Alpinia* species also contains 1,8-cineole. The essential of profiling from flower and inflorescences is still limited, therefore it could not be concluded for the typical phytochemicals of each essential oils. The two data of phytochemical profiles of galangal essential oil from fruit reveals there is no 1,8-cineole found. More further studies are required to establish the typical bioactive compounds from every plant organ of galangal genus.

6. Biological activities of galangal essential oils

Some of the phytochemicals in galangal essential oils show bioactivity. The studies on galangal essential oil bioactivity have deeply explored the capability as antioxidants, antimicrobial, anti-inflammatory, anticancer, anti-antiparasitic activities and cardiovascular impairment. These activities are closely related to traditional uses mainly as traditional medicines (Table 4).

6.1. Antioxidant activity

Galangal essential oils are rich in monoterpene hydrocarbon and oxygenated monoterpene with proven biological activity. Most cinnamic acid derivatives such as methyl cinnamate and ethyl cinnamate, have antimicrobial and antioxidant activities. The 1,8-cineole was also reported to possess antimicrobial property and was recognized as permeation enhancer [147]. All the essential oil samples from stems, rhizomes, seed, and flowers of *Alpinia nigra* showed radical scavenging activities in the DPPH assay in a dose dependent manner. Compared to butylated hydroxytoluene (BHT), it was found that the antioxidant activity in all the samples was similarly effective [59].

Cavalcanti et al. [16] reported the antioxidant activity of essential oils from the leaves of *Alpinia zerumbet*. This essential oil exhibited DPPH radical scavenging effects and other free radicals, which were determined by intracellular GSH and lipid peroxidation assays. The essential oil extracted from *Alpinia zerumbet* leaves was found to lower intracellular levels of radical oxygen species (ROS) and protect leukocyte DNA from oxidative damage. In addition, this essential oil also had the ability to reduce H_2O_2 toxicity when cells were exposure to H_2O_2 [16]. The essential oil from the flower of *Alpinia galanga* possessed moderate antioxidant activity compared with BHT and ascorbic acid. The antioxidative properties were supposed to the presence of eugenol and its derivatives in this essential oil [117].

6.2. Antimicrobial activity

Traditionally, the *Alpinia* genus have been used tp treat many infectious diseases that is suggested to have correlation with their antimicrobial activity including to the pathogenic microbes. Galangal essential oil inhibits the growth of *Staphylococcus aureus, Escherichia coli*, *Arcanobacterium pyogenes, Streptococcussuis and Pseudomonas aeruginosa* [96,148], *Salmonella typhii, Bacillus cereus, Listeria monocytogenes* [138]. The 1,8-cineole, bisabolene, and 4-allyphenyl acetate, all of which are obtained from galangal essential oils were responsible for antibacterial activity [149]. Agar disc diffusion experiment revealed anti *Propionibacterium acnes* action for galangal essential oil [150].

Alpinia galanga rhizome essential oil was proven to possess antibacterial activity on Enterohemorrhagic *Escherichia coli* O157:H7 (EHEC O157). The mechanism of antibacterial activity was by the passive permeability increase of bacterial cell membrane. The increasing permeability resulted in a crucial intracellular components efflux. This essential oil also disrupted the bacterial physiological metabolism, such as P-type ATPases activity inhibition and four virulence genes down-regulation expression which was associated with EHEC infections. That study also suggested the ability of ethyl cinnamate to suppress respiratory metabolism and the major components of this essential oil bind to the minor groove of DNA [135].

The greater galangal is a promising spice rich in antibacterial compounds for a candidate natural food preservative. The study of Zhang et al. [114] indicated that the main antibacterial compounds were in the chloroform and n-hexane fractions, suggesting the low polarities of the essential oils. That study identified four major antibacterial consisting of hydroxy cinnamaldehyde, coumaryl alcohol, cinnamaldehyde, and 1 ′-acetoxychavicol acetate (ACA). ACA has not been previously reported to possess antibacterial activity. This compound significantly affected the bacterial morphology by disrupting the cell membrane integrity, osmotic regulation, and bacterial cell adhesion and invasion. This novel compound also inhibited the expression of proteins for cell membrane and wall synthesis. Moreover, ACA increased the expression of regulating proteins for the stress oxidative, ATP synthesis, and respiratory chain.

Santos et al. [151] reported that the essential oil from red and pink variants of *Alpinia purpurata* inflorescences significantly inhibited the growth of Gram-positive and -negative bacteria. The essential oils of rhizome, pseudostem, and leaves of *Alpinia conchigera* showed weak dermatophytic fungal and bacterial inhibitory activities [14]. Ghosh et al. [59] showed that the antibacterial activity of essential oil from the rhizome of *Alpinia nigra* was due to bacterial lysis through degrading bacterial cell walls by essential oil thus affecting the cytoplasmic membrane.

*Alpinia guilin*ensis essential oils extracted by hydro-distillation from fruits, leaves and stems had a broad-spectrum antibacterial activity. These essential oils were effective to strongly inhibit the growth of four foodborne pathogens including *Bacillus subtilis, Staphylococcus aureus, Pseudomonas eruginosa,* dan *Escherichia coli.* The inhibitory activity against *S. aureus* was almost comparable with antibiotic streptomycin, although the mechanism of inhibition was different. The essential oils *of Alpinia guilinensis* was supposed to increase membrane permeability thus directly disrupted the cell structure, leading to bacterial cell shrinkage and lysis. The safety test showed that the haemolytic rates of these three essential oils on human blood cells were low, indicating their safety to use. This finding suggested the use essential oils from *Alpinia guilinensis* as natural and safe food preservatives [60].

The major compounds in the essential oil from the leaves of *Alpinia guinanensis* were 1,8-cineole, α-phellandrene, and β-pinene. This leaf essential oil exhibited a broad-spectrum antibacterial activity against foodborne pathogenic bacteria including *Bacillus subtilis, Staphylococcus aureus, Escherichia coli*, and *Pseudomonas aeruginosa*. The capability to inhibit the growth of *Staphylococcus aureus* was higher than that of streptomycin. This essential oil increased bacterial cell membrane permeability, resulting in a lysis and a leakage of intracellular electrolytes. However, the mechanism of bacterial growth inhibition differed from that of streptomycin, which inhibited protein synthesis. This essential opil is safe to human indicating low haemolytic rate. This essential oil is projected to be a natural and safe food bio-preservative [145].

The essential oils from leaves, pseudo stems, and rhizomes of *Alpinia conchigera*, showed a weak inhibition indicated by a considerably high concentration for inhibition. Nevertheless, this inhibition indicated an antimicrobial potential. Traditionally, the rhizome of *Alpinia conchige*ra has been used to treat fungal skin infections along the east coast of the Malaysian Peninsula by topical treatment [14]. The essential oil from the flower of the red cultivar of *Alpinia purpurata* inhibited the growth of *S. aureus*, a Gram-positive bacterium [127].

6.3. Anti-inflammatory activity

The 1,8-cineole from *Alpinia officinarum* essential oil exhibits various biological activities such as anti-inflammatory by combating cerulein-induced histological damage, pancreatic oedema, and NF-κB expression in rats. This compound also replenished the glutathione (GSH) depletion and enhanced anti-inflammatory IL-10 cytokine level [122]. This anti-inflammatory activity is comparable to the thalidomide as a TNF-α inhibitor. Besides, pro-inflammatory cytokines such as IL-1β, IL-6, and TNF-α also decreased [122].

Ji et al. [144] demonstrated that essential oil from the fructus of *Alpinia zerumbet* had anti-inflammatory activity in lipopolysaccharides-induced human aortic endothelial cell inflammation. The mechanism of antiinflammation was via TLR4-dependent NF-κB signaling inhibition *in vitro* and *in vivo*. That study proved the traditional uses of the fructus of *Alpinia zerumbet* in Chinese folk medicine for treatment and prevention of cardiovascular diseases and vascular disorders.

6.4. Cardiovascular impairment

It has been claimed that the methanolic fraction of *Alpinia zerumbet*'s essential oil produced an antihypertensive effect. The cardiac myocytes strained by doxorubicin-induced rats' heart malfunction appear to be improved by reduced calcium mobilization from intracellular reserves and a chemical in galangal [11,152]. Traditionally, *Alpinia zerumbet* is used to treat hypertension in Brazil. The intragastric administration of essential oil from the leaves of *Alpinia zerumbet* showed an antihypertensive effect. The mechanisms of antihypertension were by inhibiting the calcium influx and calcium mobilization from intracellular stores. This essential oil induced an aortic ring relaxation in the rats [11].

Vasorelaxant is also shown by the essential oil from the aerial part of *Alpinia zerumbet* [142]. The 1,8-cineole is the main constituent of this essential oil that responsible for vascular relaxation. Previously, Lahlou et al. [153,154] reported the decrease in arterial pressure in normotensive rats after treatment with essential oil from the leaves of *Alpinia zerumbet*. The terpinen-4-ol as the constituent of this essential oil was supposed to have the important role for the hypotensive effect. Recently, Rocha et al. [155] studied the effect of the essential oil from the leaves of *Alpinia zerumbet*. This essential oil relaxed the blood vessel by inhibiting Ca^{2+} as an activation for vasodilatation. Ca^{2+} channels blocking was induced by the three main constituents of this essential oils including 1,8-cineole, terpinen-4-ol, and p-cymene.

Holanda et al. [11] revealed that the essential oil from the *Alpinia zerumbet* demonstrate vasodilator and antihypertensive effects. The isoproterenol induced rat group treated with the essential oil showed a better autonomic and cardiovascular function in acute myocardial infarction.

Atherosclerosis is a progressive chronic condition that leads to cardiovascular diseases as one of the causes of increased global mortality. Traditionally the dried and ripe fructus of *Alpinia zerumbet* has been used in China for cardiovascular disease treatment. The study of Wang et al. [45] proved that the essential oil from the fruit of *Alpinia zerumbet* attenuated the atherosclerosis progression by reducing the development of aortic intima plaque, increasing collagen in aortic plaque, lipid profile improvement, and reducing inflammatory factors. This essential oil also inhibited the foam cell formation by increasing cholesterol efflux. The chemical constituent of the essential of from *Alpinia zerumbet* fructus directly bound to PPARγ protein to increase its stability than modulated the foam cell formation.

6.5. Anticancer activity

Galangal essential ois are suggested to possess anticancer activity by several mechanisms, although this field of study has been limitedly explored. Some studies [19,20,65] showed the cytotoxicity of galangal essential oils as one indicator of anticancer activity. The study of Hong et al. [65] showed that *(E)*-2-decenal, the most predominant compounds in essential oil of the rhizomes of *Alpinia* *coriandriodora*, was a potential anticancer. This compound was able to form DNA adducts. The *(E)*-2-decenal also possessed stronger cytotoxicity to human cancer cell lines than the *(E)*-2-octenal. The *(E)*-2-octenal had been previously reported had high cytotoxicity. Unfortunately, the *(E)*-2-decenal also possessed cytotoxic activity to non-cancerous cells higher than to human cancer cell lines. Meanwhile, the essential oils showed selective and significant cytotoxicity to cancer cells but less cytotoxicity to non-cancerous cells. However, essential oil itself had less cytotoxicity than the *(E)*-2-decenal, indicating antagonist effect among the constituents of *Alpinia coriandriodora.* In addition, the essential oil disrupted the phase cell cycle, induced apoptosis, and inhibited the migration and invasion ability of cancer cells lines. This *in vitro* study revealed the essential oil form *Alpinia coriandriodora* was a potential anticancer agent and has outstanding anticancer activity.

6.6. Antiparasitic activity

Some diseases are borne by vectors carrying parasites such as malaria and leishmaniasis. The drugs for curing parasite causing diseases are usually chemical synthetics with some adverse effects. Natural antiparasitic with the vital action on the metabolic pathway of parasites is important to investigate. Among them, the study of Pereira et al. [156] indicated the potential uses of the essential oil from the leaves of *Alpinia speciosa* (J.C.Wendl.) K. Schum as antiparasitic for leishmaniasis and chagas diseases caused by *Leishmania brasiliensis* Vianna and *Trypanosoma cruz*i Chagas, respectively. The major components in this essential oil, 1,8-cineole, camphor and sabinene were identified to have a remarkable antiparasitic activity.

Studies on the biological activity of galangal essential oil show that it is closely correlated with its phytochemical compounds. However, the studies are still limited and mainly focus on antimicrobial and antioxidant properties, and some evaluate the anti-inflammatory properties. Traditionally, galangal species are used in many disease prevention and cure, which should be further scientifically proven.

Table 4. The traditional uses of *Alpinia* species and scientifically proven bioactivity of their essential oils.

Alpinia species	Traditional uses	Ref.	Bioactivity	Ref.
Alpinia galanga	Stomach pain and discomfort, colds, bronchitis, edema, treat diuretics, chest pain, and slimming	[9,37,129,130]	Antioxidant	[71,131,132]
Alpinia galanga	Mouthwash, eczema, colitis, ulcers, digestive problems (indigestion), cholera, bad breath, bronchitis, whooping cough, chronic enteritis, and fever	[13,14,37,133,134]	Antimicrobial	[135–138]
Alpinia officinarum	To treat several symptoms including pain, inflammation, stomach-ache, cold, ringworm, tooth decay, abnormal menstruation, flatulence, abdominal pain, haemorrhoids, inflammation, general weakness	[2]	Antioxidant	[9]

Continued on the next page

Alpinia species	Traditional uses	Ref.	Bioactivity	Ref.
Alpinia officinarum	To eliminate dispelling evil wind and flatulence	[38]	-	-
Alpinia calcarata	To treat stomach ache, fever, rheumatism, diabetes, gastrointestinal problems, cough, and respiratory problems	[41–43]	Antioxidant, antimicrobial, antinociceptive, gastroprotective, antiinflammatory, and antidiabetic activities.	[43,102]
Alpinia nigra	To treat many health problems such as intestinal infection, irregular menstruation, and bone weakness.	[58]	Antioxidant and antibactericidal	[59]
Alpinia purpurata Vieill. K.Schum	For the treatments of rheumatism, sore throat, headache, and renal infection	[35,127]	Antimicrobial	[96]
Alpinia zerumbet	Arterial hypertension and anxiety treatment	[139–141]	Anti-hypertensive	[11,24,142]
Alpinia zerumbet Fructus	Treating indigestion, vomiting, and diarrhoea.	[143]	Cardiovascular activity	[144]
Alpinia oxyphylla Miq.	For treating dyspepsia, abdominal pain, diarrhoea, 'kidney' asthenia, spermatorrhoea, and poor memory	[48]	Neuroprotective, hypnosis, and sedation, and improving memory ability	[56]
Alpinia oxyphylla Miq.	Intestinal disorders, inflammatory conditions, enuresis, urethral disorders dementia, and cerebrovascular disorders	[49–51,54]	As a aphrodisiac, tonic, and anti-polyuria effects	[53]
Alpinia guinanensis	To relieve stomach ache	[145]	Antibacterial	[145]
*Alpinia nigra (*Gaertn.) B. L. Burtt.	Used as food flavouring, vegetable diet, to treat intestinal infection, irregular menstruation, and bone weakness.	[58]	Antioxidant and bactericidal	[59]
*Alpinia nigra (*Gaertn.) B. L. Burtt.	Natural preservative in the food products	[59]	Antioxidant and bactericidal	[59]
Alpinia guilinensis	Food flavouring agent for fish and meat peculiar smells	[60]	Antibacterial	[60]

Continued on the next page

Alpinia species	Traditional uses	Ref.	Bioactivity	Ref.
Alpinia conchigera Griff.	Treat fungal infections and post-partum medicine	[14]	Antifungal and antibacterial	[14]
Alpinia malaccensis	To treat nausea, vomiting and wounds along with as a seasoning agent in meat processing and as perfume.	[64]	Antioxidant, antimicrobial, anti-inflammatory	[64]
Alpinia coriandriodora	Treating stomach ache, indigestion, asthma, cold, and fever	[146]	-	-
Alpinia kwangsiensis	For abdominal pain, cold, vomiting, stomach, and traumatic injury treatment	[44]	-	-
*Alpinia katsumad*ai	For pain, abdominal distention, and diarrhoea	[63]	-	-
Alpinia japonica (Thunb.) Miq.	Lung cold, abdominal crymodynia, rheumatism, over-strained haemoptysis, menoxenia, knocks, and falls treatments	[61]	-	-

7. The applications of galangal essential oils

The applications of essential oils are diverse. Besides widely used in perfumes and cosmetics, essential oils also have medicinal applications [82]. In general, the use of essential oils is topically (apply to skin), aromatically (diffuse), and certain essential oils can be used internally (ingest). Essential oils are considered capable of providing solutions to the need for aromas that are not only pleasant but also provide benefits for the body. Essential oils have been acknowledged as a preventive medicine as herbs rather than a therapeutic treatment. Essential oil is also used in an effort to control stress, perform breathing techniques, and relaxation before medical treatment. Pure essential oil has a therapeutic effect and two recommended ways for the therapy are dripped on a diffuser and dissolved in carrier oil.

The applications of galangal essential oils are correlated with their bioactivity as shown in Table 5. The antimicrobial activity is the basis for their uses as anti-acne and preservatives for foods and their packaging. More studies are needed to explore the function of galangal essential oils as antimicrobials mainly for various food systems and pharmaceuticals. The antioxidant activity of galangal essential oils is very useful in active packaging. The ability of galangal essential oil to inhibit the growth of insect and larvicidal is the basis for their uses as insecticidal and insect repellant. Another application of galangal essential oils is for aromatherapy as vasorelaxant. However, the constraints of galangal essential oil utilization are low yield, beside their exploration in many applications are still limited.

7.1. Antimicrobial

Acne is one of inflammatory diseases occurring one cause is due to the bacterial and fungal infections on the skin. Antimicrobial activity is one of acne treatment, therefore finding out the natural antimicrobial ingredient is important to produce natural anti-acne cream. One of the candidates for antimicrobials in anti-acne cream is red galangal essential oil. *Alpinia purpurata* essential oil formulation into cream exhibited *Canda albicans* inhibition. This essential oils was dominated by β-bisabolene and β-sesquiphellandrene [157].

Table 5. The applications of galangal essential oils and their bioactivity.

Alpinia species and plant organ	The use	Ref.	Bioactivity	Ref.
Rhizome of *Alpinia purpurata* Vieill. K.Schum	Anti-acne cream	[157]	Antimicrobial	[96]
Rhizome of *Alpinia galanga*	Anesthetic for clinical application	[158]	Aanaesthetic effect	[70]
Rhizome of *Alpinia officinarum* Hance	Biodegradable polymers	[159]	Antioxidant	[9]
Inflorescences of *Alpinia purpurata* Vieill. K.Schum	Insecticides and repellents	[105]	Natural insecticides	[21]
Rhizome of *Alpinia zerumbet Fructus*	Nanoemulsion for treatment of diabetes-induced vascular endothelial injury	[160]	Anti inflammation	[144]
Aerial part of *Alpinia zerumbet*	Vasorelaxant	[142]	Vasodilator and antihypertensive	[11,153–155]
Leaves of *Alpinia guilinensis*	Natural and safe preservative	[60]	Antibacterial	[145]
Rhizome of *Alpinia galanga*	Natural antibacterial substances in active food packaging	[30]	Antibacterial	[135–138]
Rhizome of *Alpinia galanga*	Fruit active packaging	[147]	Antioxidant and antimicrobial	[85,161]
Rhizome of *Alpinia galanga*	Slimming aromatherapy	[162]	Antidepressant	[163]

7.2. Livestock and fisheries sector

In the livestock sector, essential oil from *Alpinia galanga* is used to modify the conditions of the microbiota in the rumen of livestock. Daning et al. [164] evaluated various doses of galangal essential oil in conditioning the rumen microbes to reduce CH_4 and NH_3 production. The main constituent of galangal essential oil is 1,8-cineole which has the ability as an antimicrobial. Galangal essential oil is also reported to improve the nutritional composition of milk produced by changing the amount and types of bacteria in the rumen [165].

Some essential oils exhibit anesthetics activity, which is very important in the handling of fish. Khumpirapang et al. [166] studied the activity of three compounds from *Alpinia galanga* essential oil (1,8-cineole, 4-allylphenyl acetate, and methyl eugenol) for anaesthetic effect on *Cyprinus carpio* (koi carp). That study revealed that all compounds exhibited anaesthetic effect. Methyl eugenol had the shortest induction time and the longest recovery time. Meanwhile, 4-allylphenyl acetate had longer induction time and shorter recovery time than 1,8- cineole.

7.3. Preservatives

The use of galangal essential oil as antimicrobials in packing materials is also a promising and environmentally beneficial option, particularly in fruit preservation. According to Zhou et al. [167], mangoes coated with carboxymethyl chitosan-pullulan film impregnated with 8% galangal essential oil could be stored for 9 days longer at room temperature when compared to control samples. Galangal essential oil had the potential to be used as a natural antibacterial agent in active food packaging. Nanofiber mats applied to fresh beef show that the encapsulated galangal root oil may still successfully suppress the growth of EHEC O157 [30]. *Alpinia galanga* essential oil-based nano emulsion can be exploited in the pharmaceutical industry as an antioxidant and antibacterial agent [71]. When compared to traditional essential oil (IC50 - 19 g/ml), nano emulsified essential oil (IC50 - 9 g/ml) demonstrated much higher antioxidant activity. Galangal essential oil microemulsion gel could be a potential formulation for transdermal distribution of anti-inflammatory hydrophobic drugs like flurbiprofen [168].

7.4. Active packaging

Incorporation of essential oils in active packaging increasingly has a greet appreciation. Embedding essential oils to biodegradable plastics produces active packaging with functionality to reduce packaging waste and food loss [169]. Galangal essential oils with a broad biological activity as antioxidant and antibacterial, is the advantages over petroleum-based plastics. The development of antibacterial packaging by using galangal essential oils can considerably prolong the shelf life of foods [85].

The study of Wongphan et al. [169] revealed that the extruded polylactic acid and polybutylene succinate (PLA/PBS) films blended with lesser galangal essential oils at up to 6% modified the packaging properties. The wrap of this active packaging into steamed glutinous rice, allowed the release of the majority of volatile essential oil consisted of eucalyptol, β-ocimene, geraniol, and 2-bornanone. The essential oil in this packaging delayed the fungal and bacterial growth in cooked glutinous rice and increased shelf life to more than 2-fold depending on essential oil concentration. Volatile essential oil release into headspace from film interface showed antimicrobial activities.

One constraint in embedding essential oils into the packaging materials is the uncontrolled release of the active ingredients from this oil thus decreasing the storage stability and functions. Essential oils might be stabilized before incorporating into packaging materials by encapsulation. Liang et al. [161] evaluated the performance of the nano liposome encapsuling *Alpinia galanga* essential oil in the γ-polyglutamic acid packaging. This essential oil can be released as the response to pH changes. The packaging revealed enhanced antioxidant and antimicrobial activities.

7.5. Biopesticides

Pest attack into food crops lead to a huge quantity of economic value loss. Some strategies have long been applied to control the pest infestation. The integrated pest management aim to maintain the organism population below the level of economic injury. The methods should be non-targeted organisms, and the least possible hazards to people and the environment. The uses of plant-derived bioinsecticides are interesting alternatives because these organic compounds are commonly degraded rapidly, resulting in low residue and persistence. The essential oils are one of the suitable bioinsecticides, beside plant extracts, wood ash, seed oils, leaf powders, and lectins [170].

The essential oil from *Alpinia purpurata* Vieill. K. Schum (red galangal) inflorescences showed insecticidal activity againt *Sitophillus zeamais* (maize weevil). This essential oil disrupted the nutritional status when ingested by maize weevill adult indicating by the biomass gain rate and ingested food conversion efficiency were negative or near zero. This oil exhibited no toxicity when applied directly on the cuticle of *S. zeamais* adults. The fumigant toxicity assay revealed that this essential oil killed *S. zeamais* adults but no repellent property was detected. Some oxygenated monoterpenes and monoterpene hydrocarbons are likely to be responsible for this fumigant toxicity [170].

The study of Ghosh et al. [59] showed that the essential oils from leaf, rhizome and seed of *Alpinia nigra* showed larvicidal activity. This essential oil had biting deterrent activity against female *Aedes aegypti* mosquito. The essential oil from the flower of *Alpinia purpurata* exhibited potent larvicidal activities against *Aedes aegypti* [127].

The study of Feng et al. [105], showed that insecticidal and insect-repellent activities were observed in the essential oils from various organs of *Alpinia zerumbe*t. The essential oils from stems, flower, leaves, and fruits of this plant exhibited varying degree insecticidal and repellent activities to *Tribolium castaneum* and *Liposcelis bostrychophila*. The essential oils from various organs of *Alpinia zerumbet* were characterized by seven compounds (camphene, m-cymene, o-cymene, linalool, eucalyptol, borneol, and camphor) with varying degrees of insecticidal and repellent activities. Among them, o-cymene exhibited the strongest contact toxicity and fumigant. Wu et al. [44] also showed the insecticidal activity of *Alpinia kwangsiensis* on *Lasioderma serricorne*. This essential oil exhibited fumigant and contact toxicity and became a potential natural insecticide to control insects on the stored grains and herbs.

7.6. Fragrance and aromatherapy

Fragrance is an integral part of many industries such as cosmetics, freshener, and perfumes, and also play a significant role in masking undesirable odours. The essential oils with imparting pleasant aromas are able to act as fragrance and simultaneously act as an active ingredient such as antimicrobial and antioxidant. Among the valuable essential oils used as fragrances are lavender, citrus, tea tree, eucalyptus, and other floral oils [83]. Eucalyptol or 1,8-cineole is an aromatic compound that abundantly found in galangal; essential oils. Other sources of eucalyptol are galangal essential oil, anise, chamomile, and buckwheat. Data analysis reveals that eucalyptol is safe and does not have a genotoxicity concern [171].

In aromatherapy, essential oil inhalation of volatile bioactive compounds provides psychological and physical benefits. The essential oil from *Alpinia galanga* exhibited an anti-depressive-like effect and some antidepressant compounds were found such as fenchone, eucalyptol, and α-terpineol [163]. Essential oil from red galangal obtained by distillation revealed slimming properties of rats after inhalation for 5 weeks. The major compounds in this essential oil were β-bisabolene, trans-caryophyllene, bicyclo-2-heptene, and pentadecane. This study indicated the use of red galangal essential oils for slimming aromatherapy [162].

Table 6 showed the previous research that highlighted the potential application of galangal essential oil. In general, the uses are well correlated with the bioactivity.

Table 6. Potential application of galangal essential oil.

Alpinia species	Function	Application	Ref.
Alpinia galanga	Anaesthetic for clinical application	As nano emulsion that has an anaesthetic activity and promising delivery system of *Alpinia galanga* oil	[158]
A. officinarum Hance	Biodegradable polymers	Produces functional active packaging of freshly steamed glutinous rice that reduces food loss and package waste.	[159]
Alpinia zerumbet	Vasorelaxant and antihypertensive	Treatment of hypertension	[11,142,172]
Alpinia zerumbet (Pers.) B.L.Burtt & R.M.Sm.	Effective substitutes of synthetic insecticides and repellents	Inhibit the growth of *T. castaneum* and *L. bostrychophila*	[105]
Alpinia zerumbet Fructus	Therapeutic for treatment atherosclerosis and other cardiovascular diseases	In Guizhou Province of China, folk medicine is used to treat cardiovascular disorders in clinics.	[144]
Alpinia zerumbet Fructus	Nanoemulsion for the oral delivery	Treatment of diabetes-induced vascular endothelial injury	[160]
Alpinia guilinensis	Natural and safe preservative	Inhibit the foodborne pathogens bacteria growth	[60]
Inflorescences *A. purpurata* Vieill. K.Schum	Natural insecticides	To control *S. zeamais* by fumigation	[21]
Inflorescences *A. purpurata* Vieill. K.Schum	Natural insecticides	To control *Aedes aegypty*	[22]
Alpinia guinanensis	Natural preservative	Inhibit the foodborne pathogens bacteria growth	[58]
Alpinia calcarata	Anti-inflammatory agent	Use conventional methods to treat respiratory issues, gastrointestinal issues, inflammatory illnesses, diabetes, and rheumatism	[43]
Alpinia galanga	Antibacteria	To inhibit Enterohemorrhagic *Escherichia coli* O157:H7 growth	[135]
Alpinia coriandriodora	Anticancer	Exhibit comparable cytotoxicity to A549 cells and inhibit the A549 cells proliferation	[65]
Alpinia galanga	Nutritional feedstock	To improve the quality of the nutritional composition in the milk produced	[164,165]
-	Food additive	Improve the qualitative characteristics and shelf life of pineapple juice	[173]

Continued on the next page

Alpinia species	Function	Application	Ref.
Alpinia galanga	Natural antibacterial substances in active food packaging	Inhibit the growth of EHEC O157	[30]
Alpinia speciosa (J.C.Wendl.) K. Schum	Antiparasitic in clinical treatment	To inhibit the growth of parasites *Chagas* disease and *L. brasiliensis V*ianna	[23]
Alpinia speciosa (J.C.Wendl.) K. Schum	Anti-hypertensive	Has relaxant effects on intestinal smooth muscle and neuronal excitability blockade	[24]
Alpinia galanga	Nanoemulsion of GEO	In the pharmaceutical industry, it is used as an antioxidant and antibacterial agent	[71]

Many applications of galangal essential oils are mainly based on their activity as antimicrobial and antiparasitic. Some studies revealed the applications of galangal essential oils based on their biological activities such as anticancer, improving cardiovascular health, and anti-inflammatory. However, the low yield of essential oils from galangal plant organs is still a challenge. Besides, widening the application of these essential oils based on scientifically proven their biological activity.

8. Stabilization of galangal essential oils

The application of galangal essential oil has the constraint of high hydrophobicity, resulting in a poor solubility in the aqueous phase. The occurrence of numerous unsaturated carbon chain structures contributes to the hydrophobicity. This feature also makes it susceptible to environmental factors such pH, light, temperature, etc. These factors lead to degradation and isomerization, resulting in the loss activity or generating hazardous substances. Furthermore, its specific flavor may change adversely thus affecting the flavor of the final product itself [161]. Free essential oils are sensitive to volatilization and inactivation under unfavorable environment, resulting in loss functional activities [85].

8.1. Emulsions

Several studies have employed the emulsion technique to maintain the chemical and physical qualities of galangal essential oil. Podshivalov et al. [174] used interfacial polymerization at the oil-water interface in an oil-water emulsion to create polyurethane-urea microcapsules containing galangal essential oil. In the culinary industry, galangal essential oil is produced from galangal rhizomes. The physical stability, physicochemical qualities, microbiological abundance, and scent profiles of pineapple juice was affected by galangal essential oil. Galangal essential oil emulsion can be used as a juice ingredient to improve the quality and shelf life of hazy pineapple juice [173].

8.2. Microemulsion

Microemulsion is one way to stabilize essential oils by converting water-immiscible essential oil into oil globules covered by emulsifiers in the micron size diameter. Chaiyana and Okonogi [175] prepared the microemulsion from the essential oil from the rhizomes *Alpinia galanga* consisting of 20%

water, 10% essential oil, 56% surfactant mixture, and 14% co-surfactant. The microemulsion was spontaneously formed after mixing all ingredients with the characteristics of thermodynamically stable, transparent, and low viscosity. This macroemulsion possessed a higher anticholinesterase activity than the solely native essential oil and a prospective approach for Alzheimer treatment.

8.3. Nano emulsion

Nano emulsions have been a great attention to apply in many sectors because of the improvement of active compound bioavailability. Galangal essential oils have been used for some functions and disease treatments. Carrying the bioactive compounds from essential oils is a big challenge since their constituents are volatile and poor water solubility. Many essential oil delivery systems have been designed such as nanoparticles, nano emulsions, hydrogels, and nanocrystals. have been reported in recent decades to improve the solubility and stability of essential oils. Among them, nano emulsion has good stability and biocompatibility to prevent volatilization and degradation of the components of essential oils.

The constraint of essential oil use in an aqueous-based system is poor water solubility because most essential oil constituents are hydrophobic. To increase water solubility, essential oil emulsification using a suitable surfactant will increase its miscibility with water. Recently, nano emulsion had a great attraction among emulsion systems due to its high stability and other beneficial functional properties such as increase bioactivity, bioavailability, and clinical applications. One technique in preparing nano emulsion is spontaneous nano emulsion by using low energy. A self-nanoemulsifying drug delivery system of the essential oil from *Alpinia galanga* had been prepared to increase anesthetic activity on fish [15,158].

Xu et al. [176] developed a nanocarrier for the essential oil from the Fructus of *Alpinia zerumbet* that was composed of serum albumin, dextran sulphate conjugate and sodium deoxycholate. This nano emulsion increased oral absorption and extended the circulation time, and was used to increase protective effect on vascular in diabetic rat model.

8.4. Pickering emulsions

Liang et al. [85] prepared the Pickering emulsion by stabilizing the encapsulated galangal essential oils, through co-blending into the PVA-pullulan polysaccharide polymer. This emulsion shows a slow-release effect because the release of essential oil needs double emulsion barrier, which helps to maintain the durability of foods.

It is concluded that the main constraint in galangal essential oil application is the water immiscibility. Some studies proved that emulsification can solve this problem. Some advanced technologies in emulsification, such as nano- and pickering emulsification, had been studied to stabilize the galangal essential oils. However, the industrial application of this techniques is still a challenge.

9. Safety aspects of galangal essential oils

Safety issues are crucial in the use of natural and synthetic products for humans, whether for food consumption, medicines, cosmetics, or personal care products. It is important to address scientifically proven natural products to ensure there are no adverse health side effects. Toxicological studies are also needed to ensure galangal essential oil is safe to use. However, scientific publications regarding toxicological studies of galangal essential oil are still limited and some of them are still being discussed.

Toxicological study on essential oil of *Alpinia zerumbet* leaves by Cavalcanti et al. [16], revealed that the genotoxicity on human leukocytes was dose-dependent. No induced genotoxic was observed at concentrations of 50–300 µg/mL, but cell proliferation, viability, and DNA damage was noticed at higher dose more than 500 µg/mL. *In vivo* study indicated that the essential oil at dose of 400 mg/kg did not exert peripheral blood cell mutagenicity and bone marrow in mice. That study suggested the concentration of essential oil less than 300 µg/mL or doses up to 400 mg/kg for avoiding mutagenicity.

Based on the literature, toxicological research on galangal essential oil is still limited. The available data cannot yet be used to determine the safety level of galangal; essential oil. Further research is needed to determine the safety level of galangal essential oil for both oral and topical use, including its effect on various human organs.

10. Conclusions

Almost all plant organs of the *Alpinia* genus are the source of galangal essential oils. Galangal essential oils contain many phytochemicals with the typical of 1,8-cineole mainly in rhizomes, root, and leaves, however other organs are still limitedly profiled. There are significant correlations between traditional medicinal uses of galangal essential oils with their bioactivity and scientifically proven health benefits. Stabilization by some emulsification methods is suitable to increase galangal essential oil stability and improving their applications. Galangal essential oils are potential to use in many sectors such as agriculture, food, pharmaceutical and personal care industries. The appropriate extraction method is still a challenge mainly to improve the yield along with preserving the bioactive compounds. Another challenge is exploring other *Alpinia* species, proof their health benefits, and exploring their potential uses in many sectors.

Acknowledgements

The authors are very grateful for research funding from Directorate of Research Technology, and Community Services (DRTPM), the Ministry of Education, Culture, Research, and Technology, the Republic of Indonesia through Doctoral Dissertation Research (Penelitian Disertasi Doktor, Project No. 119/E5/PG.020.00.PL/2023).

Conflict of interest

The authors declare that there are no conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

Authors contribution

First and second authors contribute to literature searching, data classification and analysis, manuscript preparation, and revisions. Third and fourth authors have a role in supervision.

References

1. Zhang WJ, Luo JG, Kong LY (2016) The genus *Alpinia*: A review of its phytochemistry and pharmacology. *World J Tradit Chinese Med* 2: 26–41. https://doi.org/10.15806/j.issn.2311-8571.2015.0026
2. Abubakar IB, Malami I, Yahaya Y, et al. (2018) A review on the ethnomedicinal uses, phytochemistry and pharmacology of *Alpinia officinarum* Hance. *J Ethnopharmacol* 224: 45–62. https://doi.org/10.1016/j.jep.2018.05.027
3. Ravindran PN, Pillai GS, Balachandran I (2012) 15-Galangal. In: Peter KV (Ed.), *Handbook of herbs and spices*, 2nd ed., Cambridge: Woodhead Publishing, 303–318. https://doi.org/10.1533/9780857095688.303
4. Ghosh S, Rangan L (2013) *Alpinia*: The gold mine of future therapeutics. *3 Biotech* 3: 173–185. https://doi.org/10.1007/s13205-012-0089-x
5. Criley RA (2014) *Alpinia* to Zingiber–zingiberales in commercial floriculture. *XXIX International Horticultural Congress on Horticulture: Sustaining Lives, Livelihoods and Landscapes (IHC2014): 1104*, 435–454. https://doi.org/10.17660/ActaHortic.2015.1104.64
6. Eram S, Mujahid M, Bagga P, et al. (2019) A review on phytopharmacological activity of *Alpinia galanga*. *Int J Pharm Pharm Sci* 11: 6–11. https://doi.org/10.22159/ijpps.2019v11i3.31352
7. Kazeminia M, Mehrabi A, Mahmoudi R (2022) Chemical composition, biological activities, and nutritional application of Asteraceae family herbs: A systematic review. *Trends Phytochem Res* 6: 187–213.
8. Olaoluwa O, Taiwo O, Nahar L, et al. (2022) Ethnopharmacology, phytochemistry and biological activities of selected African species of the genus Ficus. *Trends Phytochem Res* 6: 46–69.
9. Basri AM, Taha H, Ahmad N (2017) A review on the pharmacological activities and phytochemicals of *Alpinia officinarum* (galangal) extracts derived from bioassay-guided fractionation and isolation. *Pharmacogn Rev* 11: 43. https://doi.org/10.4103/phrev.phrev_55_16
10. Suja S, Chinnaswamy P (2008) Inhibition of in vitro cytotoxic effect evoked by *Alpinia galanga* and *Alpinia officinarum* on PC - 3 cell line. *Anc Sci Life* 27: 33–40.
11. da Cunha GH, de Moraes MO, Fechine FV, et al. (2013) Vasorelaxant and antihypertensive effects of methanolic fraction of the essential oil of *Alpinia zerumbet. Vascul Pharmacol* 58: 337–345. https://doi.org/10.1016/j.vph.2013.04.001
12. Ramanunny AK, Wadhwa S, Gulati M, et al. (2022) Journey of *Alpinia galanga* from kitchen spice to nutraceutical to folk medicine to nanomedicine. *J Ethnopharmacol* 291: 115144. https://doi.org/10.1016/j.jep.2022.115144
13. Bitari A, Oualdi I, Touzani R, et al. (2023) *Alpinia officinarum* Hance: A mini review. *Mater Today Proc* 72: 3869–3874. https://doi.org/10.1016/j.matpr.2022.10.080
14. Ibrahim H, Aziz AN, Syamsir DR, et al. (2009) Essential oils of *Alpinia conchigera* Griff. and their antimicrobial activities. *Food Chem* 113: 575–577. https://doi.org/10.1016/j.foodchem.2008.08.033
15. Khumpirapang N, Suknuntha K, Anuchapreeda S, et al. (2021) Binding effects of *Alpinia galanga* oil and its nanoemulsion 1 to GABAA receptors in rat cortical membranes. https://doi.org/10.21203/rs.3.rs-816924/v1
16. Cavalcanti BC, Ferreira JRO, Cabral IO, et al. (2012) Genetic toxicology evaluation of essential oil of *Alpinia zerumbet* and its chemoprotective effects against H2O2-induced DNA damage in cultured human leukocytes. *Food Chem Toxicol* 50: 4051–4061. https://doi.org/10.1016/j.fct.2012.03.038

17. Sahoo S, Singh S, Sahoo A, et al. (2020) Molecular and phytochemical stability of long term micropropagated greater galanga (*Alpinia galanga*) revealed suitable for industrial applications. *Ind Crops Prod* 148: 112274. https://doi.org/10.1016/j.indcrop.2020.112274
18. Xin M, Guo S, Zhang W, et al. (2017) Chemical constituents of supercritical extracts from *Alpinia officinarum* and the feeding deterrent activity against *Tribolium castaneum*. *Molecules* 22: 647. https://doi.org/10.3390/molecules22040647
19. Zhang L, Liang X, Ou Z, et al. (2020) Screening of chemical composition, anti-arthritis, antitumor and antioxidant capacities of essential oils from four Zingiberaceae herbs. *Ind Crops Prod* 149: 112342. https://doi.org/10.1016/j.indcrop.2020.112342
20. Zhang L, Pan C, Ou Z, et al. (2020) Chemical profiling and bioactivity of essential oils from *Alpinia officinarum* Hance from ten localities in China. *Ind Crops Prod* 153: 112583. https://doi.org/10.1016/j.indcrop.2020.112583
21. de Lira CS, Pontual EV, de Albuquerque LP, et al. (2015) Evaluation of the toxicity of essential oil from *Alpinia purpurata* inflorescences to *Sitophilus zeamais* (maize weevil). *Crop Prot* 71: 95–100. https://doi.org/10.1016/j.cropro.2015.02.004
22. Santos GKN, Dutra KA, Barros RA, et al. (2012) Essential oils from *Alpinia purpurata* (Zingiberaceae): Chemical composition, oviposition deterrence, larvicidal and antibacterial activity. *Ind Crops Prod* 40: 254–260. https://doi.org/10.1016/j.indcrop.2012.03.020
23. Pereira PS, Maia AJ, Duarte AE, et al. (2018) Cytotoxic and anti-kinetoplastid potential of the essential oil of *Alpinia speciosa* K. Schum. *Food Chem Toxicol* 119: 387–391. https://doi.org/10.1016/j.fct.2018.01.024
24. Santos BA, Roman-Campos D, Carvalho MS, et al. (2011) Cardiodepressive effect elicited by the essential oil of *Alpinia specios*a is related to L-type Ca^{2+} current blockade. *Phytomedicine* 18: 539–543. https://doi.org/10.1016/j.phymed.2010.10.015
25. da Cruz JD, Mpalantinos MA, Ramos A de S, et al. (2020) Chemical standardization, antioxidant activity and phenolic contents of cultivated *Alpinia zerumbet* preparations. *Ind Crops Prod* 151: 112495. https://doi.org/10.1016/j.indcrop.2020.112495
26. Sethunga M, Ranaweera K, Gunathilake K, et al. (2022) Recent advances in the extraction methods of essential oils and oleoresins from plant materials and its potential applications: A comprehensive review. *J Food Bioprocess Eng* 5: 151–167.
27. Dhifi W, Bellili S, Jazi S, et al. (2016) Essential oils' chemical characterization and investigation of some biological activities: A critical review. *Medicines* 3: 25. https://doi.org/10.3390/medicines3040025
28. Olalere OA, Gan CY, Taiwo AE, et al. (2024) Essential oils: Sustainable extraction techniques and nutraceuticals perspectives. In: Sarkar T, Pati S (Eds.), *Bioactive Extraction and Application in Food and Nutraceutical Industries,* Springer, 373–389. https://doi.org/10.1007/978-1-0716-3601-5_15
29. Van HT, Thang TD, Luu TN, et al. (2021) An overview of the chemical composition and biological activities of essential oils from: *Alpinia* genus (Zingiberaceae). *RSC Adv* 11: 37767–37783. https://doi.org/10.1039/D1RA07370B
30. Zhou C, Abdel-Samie MA, Li C, et al. (2020) Active packaging based on swim bladder gelatin/galangal root oil nanofibers: Preparation, properties and antibacterial application. *Food Packag Shelf Life* 26: 100586. https://doi.org/10.1016/j.fpsl.2020.100586

31. Aziman N, Abdullah N, Noor ZM, et al. (2014) Phytochemical profiles and antimicrobial activity of aromatic Malaysian herb extracts against food-borne pathogenic and food spoilage microorganisms. *J Food Sci* 79: M583–M592. https://doi.org/10.1111/1750-3841.12419
32. Das G, Patra JK, Gonçalves S, et al. (2020) Galangal, the multipotent super spices: A comprehensive review. *Trends Food Sci Technol* 101: 50–62. https://doi.org/10.1016/j.tifs.2020.04.032
33. Kress WJ, Liu AZ, Newman M, et al. (2005) The molecular phylogeny of *Alpinia* (Zingiberaceae): A complex and polyphyletic genus of gingers. *Am J Bot* 92: 167–178. https://doi.org/10.3732/ajb.92.1.167
34. Victório CP (2011) Therapeutic value of the genus Alpinia, Zingiberaceae. *Rev Bras Farmacogn* 21: 194–201. https://doi.org/10.1590/S0102-695X2011005000025
35. Palanirajan A, Kannappan P, Kanniappan GV (2022) Anticancer activity of *Alpinia purpurata* (Vieill) K. Schum. against MNU and testosterone induced prostate cancer in male Wistar albino rats. *Pharmacol Res-Mod Chinese Med* 3: 100105. https://doi.org/10.1016/j.prmcm.2022.100105
36. Liang W, Ge X, Lin Q, et al. (2024) Assembly mechanism of glycosylated soybean protein isolate-chitosan nanocomposite particles and its Pickering emulsion construction for stabilization of *Alpinia galanga* essential oil: A mechanistic investigation. *Ind Crops Prod* 217: 118869. https://doi.org/10.1016/j.indcrop.2024.118869
37. Liu P, Wu SL, Wang T, et al. (2023) Four new phenolic compounds from the fruits of *Alpinia galanga*. *Phytochem Lett* 55: 75–79. https://doi.org/10.1016/j.phytol.2023.04.001
38. Ding P, Yang L, Feng C, et al. (2019) Research and application of *Alpinia officinarum* in medicinal field. *Chinese Herb Med* 11: 132–140. https://doi.org/10.1016/j.chmed.2019.04.003
39. Rahman MA, Rahman MM, Ahmed N (2012) Essential oil of *Alpinia calcarata* Rosc. Rhizome: Heals inflammation and nociception in animal models. *J Biol Act Prod Nat* 2: 365–376. https://doi.org/10.1080/22311866.2012.10719145
40. Perveen R, Islam F, Khanum J, et al. (2012) Preventive effect of ethanol extract of *Alpinia calcarata* Rosc on Ehrlich's ascitic carcinoma cell induced malignant ascites in mice. *Asian Pac J Trop Med* 5: 121–125. https://doi.org/10.1016/S1995-7645(12)60009-1
41. Hema PS, Nair MS (2009) Flavonoids and other constituents from the rhizomes of *Alpinia calcarata. Biochem Syst Ecol* 37: 52–54. https://doi.org/10.1016/j.bse.2009.01.001
42. Ramya R, Kalaiselvi M, Narmadha R, et al. (2015) Secondary metabolite credentials and in vitro free radical scavenging activity of *Alpinia calcarat*a. *J Acute Med* 5: 33–37. https://doi.org/10.1016/j.jacme.2015.02.005
43. Erusappan T, Paramasivam S, Ekambaram SP (2022) Identification of galangin as the bioactive compound from *Alpinia calcarata* (Haw.) Roscoe rhizomes to inhibit IRAK-1/MAPK/NF-κB p65 and JAK-1 signaling in LPS stimulated RAW 264.7 cells. *J Ethnopharmacol* 288: 114975. https://doi.org/10.1016/j.jep.2022.114975
44. Wu Y, Zhang WJ, Huang DY, et al. (2015) Chemical compositions and insecticidal activities of *Alpinia kwangsiensis* essential oil against Lasioderma serricorne. *Molecules* 20: 21939–21945. https://doi.org/10.3390/molecules201219818
45. Wang S, Xiang J, Zhang G, et al. (2024) Essential oil from Fructus *Alpinia zerumbet* ameliorates atherosclerosis by activating PPARγ-LXRα-ABCA1/G1 signaling pathway. *Phytomedicine* 123: 155227. https://doi.org/10.1016/j.phymed.2023.155227

46. Chan EWC, Wong SK (2015) Phytochemistry and pharmacology of ornamental gingers, Hedychium coronarium and *Alpinia purpurata*: A review. *J Integr Med* 13: 368–379. https://doi.org/10.1016/S2095-4964(15)60208-4
47. Raj CA, Ragavendran P, Sophia D, et al. (2012) Evaluation of in vitro antioxidant and anticancer activity of *Alpinia purpurata*. *Chin J Nat Med* 10: 263–268. https://doi.org/10.3724/SP.J.1009.2012.00263
48. He ZH, Ge W, Yue GGL, et al. (2010) Anti-angiogenic effects of the fruit of *Alpinia oxyphylla. J Ethnopharmacol* 132: 443–449. https://doi.org/10.1016/j.jep.2010.08.024
49. Yu SH, Kim HJ, Jeon SY, et al. (2020) Anti-inflammatory and anti-nociceptive activities of *Alpinia oxyphylla* Miquel extracts in animal models. *J Ethnopharmacol* 260: 112985. https://doi.org/10.1016/j.jep.2020.112985
50. Xie J, Sun B, Wang S, et al. (2009) Isolation and purification of nootkatone from the essential oil of fruits of *Alpinia oxyphylla* Miquel by high-speed counter-current chromatography. *Food Chem* 117: 375–380. https://doi.org/10.1016/j.foodchem.2009.04.011
51. Cheng CY, Chiang S, Kao ST, et al. (2021) *Alpinia oxyphylla* Miq extract reduces cerebral infarction by downregulating JNK-mediated TLR4/T3JAM-and ASK1-related inflammatory signaling in the acute phase of transient focal cerebral ischemia in rats. *Chin Med* 16: 1–21. https://doi.org/10.1186/s13020-021-00495-2
52. Qi Y, Cheng X, Jing H, et al. (2019) Effect of *Alpinia oxyphylla*—Schisandra chinensis herb pair on inflammation and apoptosis in Alzheimer’s disease mice model. *J Ethnopharmacol* 237: 28–38. https://doi.org/10.1016/j.jep.2019.03.029
53. Dong J, Zhou M, Qin Q, et al. (2023) Structurally diverse new eudesmane sesquiterpenoids with anti-inflammatory activity from the fruits of *Alpinia oxyphylla*. *Bioorg Chem* 134: 106431. https://doi.org/10.1016/j.bioorg.2023.106431
54. Wang M, Bi W, Fan K, et al. (2018) Ameliorating effect of *Alpinia oxyphylla*—Schisandra chinensis herb pair on cognitive impairment in a mouse model of Alzheimer’s disease. *Biomed Pharmacother* 97: 128–135. https://doi.org/10.1016/j.biopha.2017.10.088
55. Tie Y, Sun Z, Tong X, et al. (2024) Multi-omic analysis revealed the therapeutic mechanisms of *Alpinia oxyphylla* fructus water extract against bladder overactivity in spontaneously hypertensive rats. *Phytomedicine* 123: 155154. https://doi.org/10.1016/j.phymed.2023.155154
56. Qiu C, Mu L, Wang J, et al. (2023) Sesquiterpenoids from the fruits of *Alpinia oxyphylla* Miq. and their neuroprotective effect. *Phytochemistry* 211: 113680. https://doi.org/10.1016/j.phytochem.2023.113680
57. Deng J, He B, He D, et al. (2016) A potential biopreservative: Chemical composition, antibacterial and hemolytic activities of leaves essential oil from *Alpinia guinanensis*. *Ind Crops Prod* 94: 281–287. https://doi.org/10.1016/j.indcrop.2016.09.004
58. Roy B, Swargiary A, Giri BR (2012) *Alpinia nigra* (Family Zingiberaceae): An anthelmintic medicinal plant of north-east India. *Adv Life Sci* 2: 39–51. https://doi.org/10.5923/j.als.20120203.01
59. Ghosh S (2014) Chemical composition and bioactivity studies of *Alpinia nigra* essential oils. *Ind Crops Prod* 53: 111–119. https://doi.org/10.1016/j.indcrop.2013.12.026
60. Chen Z, He B, Zhou J, et al. (2016) Chemical compositions and antibacterial activities of essential oils extracted from *Alpinia guilinensis* against selected foodborne pathogens. *Ind Crops Prod* 83: 607–613. https://doi.org/10.1016/j.indcrop.2015.12.063
61. Li QM, Luo JG, Wang XB, et al. (2013) Sesquiterpenes from the rhizomes of *Alpinia japonica* and their inhibitory effects on nitric oxide production. *Fitoterapia* 86: 29–34.https://doi.org/10.1016/j.fitote.2013.01.015

62. Wang CY, Song ZM, He CL, et al. (2017) A constituent of *Alpinia katsumadai* suppresses allergic airway inflammation. *Phytochem Lett* 22: 149–153. https://doi.org/10.1016/j.phytol.2017.09.009
63. Pogačar MŠ, Klančnik A, Bucar F, et al. (2015) *Alpinia katsumadai* extracts inhibit adhesion and invasion of Campylobacter jejuni in animal and human foetal small intestine cell lines. *Phyther Res* 29: 1585–1589. https://doi.org/10.1002/ptr.5396
64. Mahawer S, Kumar R, Prakash O, et al. (2023) A review of phytochemical and pharmacological properties of *Alpinia malaccensis* (Burm. F.) Roscoe.(Zingiberaceae). *Curr Top Med Chem* 23: 1964–1972. https://doi.org/10.2174/1568026623666230522104104
65. Hong Y, Liu X, Wang H, et al. (2022) Chemical composition, anticancer activities and related mechanisms of the essential oil from *Alpinia coriandriodora* rhizome. *Ind Crops Prod* 176: 114328. https://doi.org/10.1016/j.indcrop.2021.114328
66. Wu Y, Zhang WJ, Huang DY, et al. (2015) Chemical Compositions and Insecticidal Activities of A*lpinia kwangsiensis* Essential Oil against Lasioderma serricorne. *Molecules* 20: 21939–21945.
67. Jantan I, Ahmad F, Ahmad AS (2004) Constituents of the rhizome and seed oils of greater galangal *Alpinia galangal* (L.) Willd. from Malaysia. *J Essent Oil Res* 16: 174–176. https://doi.org/10.1080/10412905.2004.9698687
68. Raina AP, Verma SK, Abraham Z (2014) Volatile constituents of essential oils isolated from *Alpinia galanga* Willd. (L.) and *A. officinarum* Hance rhizomes from North East India. *J Essent Oil Res* 26: 24–28. https://doi.org/10.1080/10412905.2013.822430
69. Nampoothiri SV, Menon AN, Esakkidurai T, et al. (2016) Essential oil composition of *Alpinia calcarata* and *Alpinia galanga* rhizomes-a comparative study. *J Essent Oil Bear Plants* 19: 82–87. https://doi.org/10.1080/0972060X.2015.1126534
70. Khumpirapang N, Pikulkaew S, Anuchapreeda S, et al. (2018) *Alpinia galanga* oil—A new natural source of fish anaesthetic. *Aquac Res* 49: 1546–1556. https://doi.org/10.1111/are.13609
71. Singh S, Sahoo S, Sahoo BC, et al. (2021) Enhancement of bioactivities of rhizome essential oil of *Alpinia galanga* (Greater galangal) Through Nanoemulsification. *J Essent Oil-Bear Plants* 24: 648–657. https://doi.org/10.1080/0972060X.2021.1951847
72. Lin LY, Shen KH, Yeh XY, et al. (2016) Integrated process for production of galangal acetate, the 'Wasabi-Like' spicy compound, and analysis of essential oils of rhizoma *Alpinia officinarum* (Hance) Farw. *J Food Sci* 81: H1565–H1575. https://doi.org/10.1111/1750-3841.13326
73. Wei Y, Sui D, Xu H, et al. (2017) Atractylodes lancea rhizome water extract reduces triptolide-induced toxicity and enhances anti-inflammatory effects. *Chin J Nat Med* 15: 905–911.
74. Nguyen DD, Saensouk S, Nguyen van C, et al. (2023) Taxonomic notes of *Alpinia* subsect. Catimbium (Zingiberaceae) in Vietnam: The first record of *Alpinia nobilis* and description of a new species *Alpinia hoangviet. Biodiversitas* 24: 5293–5301. https://doi.org/10.13057/biodiv/d241010
75. Yuan Y, Lin LJ, Huang XB, et al. (2017) Analysis of the essential oils of *Alpiniae officinarum* Hance in different extraction methods. *IOP Conf Ser: Mater Sci Eng* 231: 012112. https://doi.org/10.1088/1757-899X/231/1/012112
76. Sukardi S, Pulungan MH, Asmara SNL (2022) Pulsed electric field energy calculation to damage red galangal (*Alpinia purpurata* K. Scumm) rhizome slices and its essential oil yield and quality with hydrodistillation. *Ces a Slov Farm Cas Ces Farm Spol a Slov Farm Spol* 71: 103–105. https://doi.org/10.5817/CSF2022-3-103

77. Ge X, Liang Q, Long Y, et al. (2022) Assessment of fresh *Alpinia galanga* (*A. galanga*) drying techniques for the chemical composition of essential oil and its antioxidant and biological activity. *Food Chem* 392: 133314. https://doi.org/10.1016/j.foodchem.2022.133314
78. Kawai H, Kuraya E, Touyama A, et al. (2021) Improved yield and antioxidant activity of essential oil from *Alpinia zerumbet* (Zingiberaceae) leaves by underwater shockwave pretreatment. *Food Bioprod Process* 125: 134–140. https://doi.org/10.1016/j.fbp.2020.11.003
79. Sethunga M, Ranaweera K, Munaweera I, et al. (2020) Recent advances in the extraction methods of essential oils and oleoresins from plant materials and its potential applications: A comprehensive review. *J Food Bioprocess Eng* 5: 151–167.
80. Nguyễn TAT, Huỳnh TĐ, Natthakan R (2019) Extraction and encapsulation of lesser galangal (*Alpinia officinarum)* essential oil using microwave pretreatment and spray drying. *Tạp chí Nông nghiệp và Phát triển* 18: 57–63. https://doi.org/10.52997/jad.9.03.2019
81. Ghasemy-Piranloo F, Kavousi F, Dadashian S (2020) Comparison for the production of essential oil by conventional, novel and biotechnology methods. https://doi.org/10.22541/au.160315281.12110663/v1
82. Rios JL (2016) Chapter 1—Essential oils: What they are and how the terms are used and defined. In: Preedy VR (Ed.), *Essential Oils in Food Preservation, Flavor and Safety,* 3–10. https://doi.org/10.1016/B978-0-12-416641-7.00001-8
83. Sharmeen JB, Mahomoodally FM, Zengin G, et al. (2021) Essential oils as natural sources of fragrance compounds for cosmetics and cosmeceuticals. *Molecules* 26: 666. https://doi.org/10.3390/molecules26030666
84. Van HT, Le NT, Huynh NTA, et al. (2022) Chemical composition and antibacterial activities of essential oils from rhizomes and aerial parts of *Homalomena cochinchinensis* (*Araceae*). *Nat Prod Res* 36: 3129–32. https://doi.org/10.1080/14786419.2021.1939333
85. Liang W, Ge X, Lin Q, et al. (2024) Ternary composite degradable plastics based on Alpinia galanga essential oil Pickering emulsion templates: A potential multifunctional active packaging. *Int J Biol Macromol* 257: 128580. https://doi.org/10.1016/j.ijbiomac.2023.128580
86. Hoch CC, Petry J, Griesbaum L, et al. (2023) 1,8-cineole (eucalyptol): A versatile phytochemical with therapeutic applications across multiple diseases. *Biomed Pharmacother* 167: 115467. https://doi.org/10.1016/j.biopha.2023.115467
87. Jirovetz L, Buchbauer G, Shafi MP, et al. (2003) Analysis of the essential oils of the leaves, stems, rhizomes and roots of the medicinal plant *Alpinia galanga* from southern India. *Acta Pharm* 53: 73–82.
88. Raj G, Pradeep DP, Yusufali C, et al. (2013) Chemical profiles of volatiles in four *Alpinia* species from Kerala, South India. *J Essent Oil Res* 25: 97–102. https://doi.org/10.1080/10412905.2012.751058
89. Akhtar P, Ali M, Mir SR, et al. (2004) Volatile constituents of rhizomes of *Alpinia galanga* (Linn.) Willd. *J Essent Oil Bear Plants* 7: 243–246. https://doi.org/10.1080/0972-060X.2004.10643400
90. Charles DJ, Simon JE, Singh NK (1992) The essential oil of *Alpinia galanga* Willd. *J Essent Oil Res* 4: 81–82. https://doi.org/10.1080/10412905.1992.9698016
91. Sripor W, Jinda N (2014) Effect of *Alpinia galangal* essential oil on bacteria spoilage. *The 26 th Meeting of the Thai Society for Biotechnology a International Conference, Thailand*, 1–6.
92. Pripdeevech P, Nuntawong N, Wongpornchai S (2009) Composition of essential oils from the rhizomes of three *Alpinia* species grown in Thailand. *Chem Nat Compd* 45: 562–564. https://doi.org/10.1007/s10600-009-9367-1

93. Hamad A, Alifah A, Permadi A, et al. (2016) Chemical constituents and antibacterial activities of crude extract and essential oils of *Alpinia galanga* and *Zingiber officinale*. *Int Food Res J* 23: 837.
94. Wu Y, Wang Y, Li ZH, et al. (2014) Composition of the essential oil from *Alpinia galanga* rhizomes and its bioactivity on *Lasioderma serricorne*. *Bull Insectol* 67: 247–254.
95. Arambewela LSR, Arawwawala M, Owen NL, et al. (2007) Volatile oil of *Alpinia galanga* willd. of Sri Lanka. *J Essent Oil Res* 19: 455–456. https://doi.org/10.1080/10412905.2007.9699950
96. Rialita T, Radiani H, Alfiah D (2019) Antimicrobial activity of the combination of red galangal (*Alpinia purpurata* K. Schum) and cinnamon (*Cinnamomum burmanii*) essential oils on Escherichia coli and Staphylococcus aureus bacteria. *J Phys Conf Ser* 1217: 012132. https://doi.org/10.1088/1742-6596/1217/1/012132
97. Sukardi S, Pulungan MH, Asmara SNL (2022) Pulsed electric field energy calculation to damage red galangal (*Alpinia purpurata*, K. Scumm) rhizome slices and its essential oil yield and quality with hydrodistillation. *Ces a Slov Farm Cas Ces Farm Spol a Slov Farm Spol* 71: 103–115. https://doi.org/10.5817/CSF2022-3-103
98. Rana VS, Verdeguer M, Blazquez MA (2010) GC and GC/MS analysis of the volatile constituents of the oils of *Alpinia galanga* (L.) Willd and *A. officinarum* Hance rhizomes. *J Essent Oil Res* 22: 521–524. https://doi.org/10.1080/10412905.2010.9700388
99. Wu J, Lei LW, Mei WL, et al. (2012) High-level 1, 8-cineole in the *Alpinia officinarum* essential oil from Hainan Island of China. *Chem Nat Compd* 48: 325–326. https://doi.org/10.1007/s10600-012-0238-9
100. Tram Ngoc L, Yamauchi R, Kato K (2001) Volatile components of the essential oils in galanga (*Alpinia officinarum* Hance) from Vietnam. *Food Sci Technol Res* 7: 303–306. https://doi.org/10.3136/fstr.7.303
101. Chandrakanthan M, Handunnetti SM, Premakumara GSA, et al. (2020) Topical anti-Inflammatory activity of essential oils of *Alpinia calcarata* Rosc., its main constituents, and possible mechanism of action. *Evidence-Based Complementary Altern Med* 2020: 2035671. https://doi.org/10.1155/2020/2035671
102. Nampoothiri SV, Venugopalan VV, Joy B, et al. (2012) Comparison of essential oil composition of three ginger cultivars from sub Himalayan region. *Asian Pac J Trop Biomed* 2: S1347–S1350. https://doi.org/10.1016/S2221-1691(12)60414-6
103. Poonkodi K, Baranika SK V, Udayakumar P, et al. (2017) Chemical composition and Anti-inflammatory potential of essential oil of *Alpinia calcarata* Rosc.-grown in South India. *Int J Pharm Sci Rev Res* 42: 207.
104. Rout PK, Sahoo S, Rath SP, et al. (2005) Analysis of the leaf, rhizome and root oils of two accessions of *Alpinia calcarata* rosc. cultivated at Bhubaneswar. *J Essent Oil Res* 17: 398–400. https://doi.org/10.1080/10412905.2005.9698941
105. Feng YX, Zhang X, Wang Y, et al. (2021) The potential contribution of cymene isomers to insecticidal and repellent activities of the essential oil from *Alpinia zerumbet*. *Int Biodeterior Biodegrad* 157: 105138. https://doi.org/10.1016/j.ibiod.2020.105138
106. Saikia J, Sarkar A, Washmin N, et al. (2023) Effect of postharvest drying on physicochemical properties, volatile yield, composition, and sensory attributes of *Alpinia zerumbet* (shell ginger) rhizome. *Ind Crops Prod* 198: 116719. https://doi.org/10.1016/j.indcrop.2023.116719

107. Wu B, Gan A, Wang R, et al. (2023) Alpinia oxyphylla Miq. volatile oil ameliorates depressive behaviors and inhibits neuroinflammation in CUMS-exposed mice by inhibiting the TLR4-medicated MyD88/NF-κB signaling pathway. *J Chem Neuroanat* 130: 102270. https://doi.org/10.1016/j.jchemneu.2023.102270
108. Trung HT, Giang LD, Thuan VT, et al. (2023) Chemical Composition of Essential Oils Extracted from the Leaves and Rhizomes of *Alpinia hongiaoensis* Tagane.(Zingiberaceae) growing Wild in Vietnam. *J Essent Oil Bear Plants* 26: 396–402. https://doi.org/10.1080/0972060X.2023.2187708
109. Wu Y, Zhang WJ, Huang DY, et al. (2015) Chemical compositions and insecticidal activities of Alpinia kwangsiensis essential oil against *Lasioderma serricorne*. *Molecules* 20: 21939–21945.
110. Yodha AWM, Badia E, Musdalipah, et al. (2023) Essential oils of *Alpinia monopleura* and their antibacterial and antioxidant activity. *Molekul* 18: 80–88. https://doi.org/10.20884/1.jm.2023.18.1.6265
111. Tra NT, Ha NX, Tuyen NV, et al. (2023) Essential oils of *Alpinia vietnamica* rhizomes and leaves: Chemical composition, cytotoxicity, α-glucosidase inhibition, and molecular docking approach. *Nat Prod Commun* 18: 10. https://doi.org/10.1177/1934578X231206280
112. Jusoh S, Sirat HM, Ahmad F (2013) Essential oils of *Alpinia rafflesiana* and their antimicrobial activities. *Natural Product Communications,* 8: 9. https://doi.org/10.1177/1934578X1300800933
113. Raina AP, Abraham Z (2017) Essential oil profiling of *Alpinia* species from southern India. *Indian J Exp Biol* 55: 776–781.
114. Zhang D, Zou L, Wu DT, et al. (2021) Discovery of 1'-acetoxychavicol acetate (ACA) as a promising antibacterial compound from galangal (*Alpinia galanga* (Linn.) Willd). *Ind Crops Prod* 171: 113883. https://doi.org/10.1016/j.indcrop.2021.113883
115. Mallavarapu GR, Rao L, Ramesh S, et al. (2002) Composition of the volatile oils of *Alpinia galanga* rhizomes and leaves from India. *J Essent Oil Res* 14: 397–399. https://doi.org/10.1080/10412905.2002.9699900
116. Tang G, Chen Y, Jiang Y, et al. (2018) Green human resource management practices: scale development and validity. *Asia Pac J Hum Resour* 56: 31–55. https://doi.org/10.1111/1744-7941.12147
117. Tian Y, Jia X, Wang Q, et al. (2022) Antioxidant, antibacterial, enzyme inhibitory, and anticancer activities and chemical composition of *Alpinia galanga* flower essential oil. *Pharmaceuticals* 15: 1069. https://doi.org/10.3390/ph15091069
118. Feng YX (2020) Contact toxicity and repellent efficacy of Valerianaceae spp. to three stored-product insects and synergistic interactions between two major compounds camphene and bornyl acetate. *Ecotoxicol Environ Saf* 190: 110106. https://doi.org/10.1016/j.ecoenv.2019.110106
119. Eumkeb G, Sakdarat S, Siriwong S (2010) Reversing β-lactam antibiotic resistance of *Staphylococcus aureus* with galangin from *Alpinia officinarum* Hance and synergism with ceftazidime. *Phytomedicine* 18: 40–45. https://doi.org/10.1016/j.phymed.2010.09.003
120. Gazal M, Valente MR, Acosta BA, et al. (2014) Neuroprotective and antioxidant effects of curcumin in a ketamine-induced model of mania in rats. *Eur J Pharmacol* 724: 132–139. https://doi.org/10.1016/j.ejphar.2013.12.028
121. Reid K, Wright V, Omoregie S (2016) Anticancer properties of *Alpinia officinarum* (lesser galangal)—A mini review. *Int J Adv Res* 4: 300–306. https://doi.org/10.21474/IJAR01/380
122. Lima PR, De Melo TS, Carvalho KMMB, et al. (2013) 1,8-cineole (eucalyptol) ameliorates cerulein-induced acute pancreatitis via modulation of cytokines, oxidative stress and NF-κB activity in mice. *Life Sci* 92: 1195–1201. https://doi.org/10.1016/j.lfs.2013.05.009

123. Dhakad AK, Pandey V V, Beg S, et al. (2018) Biological, medicinal and toxicological significance of *Eucalyptus* leaf essential oil: A review. *J Sci Food Agric* 98: 833–848. https://doi.org/10.1002/jsfa.8600

124. Cai Z-M, Peng J-Q, Chen Y, et al. (2021) 1, 8-Cineole: A review of source, biological activities, and application. *J Asian Nat Prod Res* 23: 938–954. https://doi.org/10.1080/10286020.2020.1839432

125. Raina AP, Abraham Z (2016) Chemical profiling of essential oil of *Kaempferia galanga* L. germplasm from India. *J Essent oil Res* 28: 1077165. https://doi.org/10.1080/10412905.2015.1077165

126. Santos MS, Jezler CN, Oliveira A de, et al. (2012) Harvest time and plant age on the content and chemical composition of the essential oil of *Alpinia zerumbet. Horticultura Brasileira,* 30: 385–390. https://doi.org/10.1590/S0102-05362012000300005

127 Chan EWC, Wong SK (2015) Phytochemistry and pharmacology of ornamental gingers, Hedychium coronarium and *Alpinia purpurata*: A review. *J Integr Med* 13: 368–379. https://doi.org/10.1016/S2095-4964(15)60208-4

128. Kanjilal PB, Kotoky R, Couladis M (2010) Essential oil composition of leaf and rhizome oil of *Alpinia nigra (*Gaertner) BL Burtt. from Northeast India. *J Essent Oil Res* 22: 358–359. https://doi.org/10.1080/10412905.2010.9700345

129 Aljobair MO (2022) Chemical composition, antimicrobial properties, and antioxidant activity of galangal rhizome. *Food Sci Technol* 42: e45622. https://doi.org/10.1590/fst.45622

130. Eram S, Mujahid MD, Bagga P, et al. (2019) A review on phytopharmacological activity of *Alpinia galanga. Int J Pharm Pharm Sci* 11: 6–11. https://doi.org/10.22159/ijpps.2019v11i3.31352

131. Mahae N, Chaiseri S (2009) Antioxidant activities and antioxidative components in extracts of *Alpinia galanga* (L.) Sw. *Agric Nat Resour* 43: 358–369.

132. Mandal D, Sarkar T, Chakraborty R (2022) Critical review on nutritional, bioactive, and medicinal potential of spices and herbs and their application in food fortification and nanotechnology. *Appl Biochem Biotechnol* 195: 1319–1513. https://doi.org/10.1007/s12010-022-04132-y

133. Ramanunny AK, Wadhwa S, Gulati M, et al. (2022) Journey of *Alpinia galanga* from kitchen spice to nutraceutical to folk medicine to nanomedicine. *J Ethnopharmacol* 291: 115144. https://doi.org/10.1016/j.jep.2022.115144

134. Sahoo S, Singh S, Sahoo A, et al. (2020) Molecular and phytochemical stability of long term micropropagated greater galanga (*Alpinia galanga*) revealed suitable for industrial applications. *Ind Crops Prod* 148: 112274. https://doi.org/10.1016/j.indcrop.2020.112274

135. Zhou C, Li C, Siva S, et al. (2021) Chemical composition, antibacterial activity and study of the interaction mechanisms of the main compounds present in the *Alpinia galanga* rhizomes essential oil. *Ind Crops Prod* 165: 113441. https://doi.org/10.1016/j.indcrop.2021.113441

136. Budiati T, Suryaningsih W, Umaroh S, et al. (2018) Antimicrobial activity of essential oil from Indonesian medicinal plants against food-borne pathogens. *IOP Conf Ser Earth Environ Sci* 207: 012036. https://doi.org/10.1088/1755-1315/207/1/012036

137. Budiati T, Wibisono Y, Pambayun RA, et al. (2020) Inhibition of Listeria monocytogenes by natural antimicrobial. *IOP Conf Ser Earth Environ Sci* 411: 012042. https://doi.org/10.1088/1755-1315/411/1/012042

138. Eff ARY, Rahayu ST (2016) The antibacterial effects of essential oil from galangal rhizome *Alpinia galanga* (Linn.) pierreon rat (*Rattus norvegicus* L.) were infected by *Salmonella typhi*. *Asian J Pharm Clin Res* 9: 189–193.

139. Xiao T, Huang J, Wang X, Wu L, Zhou X, Jiang F, Shen X, et al. (2020) Alpinia zerumbet and its potential use as an herbal medication for atherosclerosis: Mechanistic insights from cell and rodent studies. *Lifestyle Genomics* 13: 138–145. https://doi.org/10.1159/000508818
140. Cunha GH da, Moraes MO de, Fechine FV, et al. (2013) Vasorelaxant and antihypertensive effects of methanolic fraction of the essential oil of *Alpinia zerumbet*. *Vascul Pharmacol* 58: 337–345. https://doi.org/10.1016/j.vph.2013.04.001
141. Cruz JD d., Mpalantinos MA, Ramos A de S, et al. (2020) Chemical standardization, antioxidant activity and phenolic contents of cultivated *Alpinia zerumbet* preparations. *Ind Crops Prod* 151: 112495. https://doi.org/10.1016/j.indcrop.2020.112495
142. Pinto N V, Assreuy AMS, Coelho-de-Souza AN, et al. (2009) Endothelium-dependent vasorelaxant effects of the essential oil from aerial parts of *Alpinia zerumbet* and its main constituent 1, 8-cineole in rats. *Phytomedicine* 16: 1151–1155. https://doi.org/10.1016/j.phymed.2009.04.007
143. Xiao T, Wu A, Wang X, et al. (2024) Anti-hypertensive and composition as well as pharmacokinetics and tissues distribution of active ingredients from *Alpinia zerumbet*. *Fitoterapia* 172: 105753. https://doi.org/10.1016/j.fitote.2023.105753
144. Ji Y, Shi T, Zhang Y, et al. (2019) Essential oil from Fructus *Alpinia zerumbet* (fruit of Alpinia zerumbet (Pers.) Burtt. et Smith) protected against aortic endothelial cell injury and inflammation in vitro and in vivo. *J Ethnopharmacol* 237: 149–158. https://doi.org/10.1016/j.jep.2019.03.011
145. Deng J, He B, He D, et al. (2016) A potential biopreservative: Chemical composition, antibacterial and hemolytic activities of leaves essential oil from *Alpinia guinanensi*s. *Ind Crops Prod* 94: 281–287. https://doi.org/10.1016/j.indcrop.2016.09.004
146. Van HT, Dam SM, Phan UTX, et al. (2022) Chemical diversity of essential oils of rhizomes of six species of Zingiberaceae family. *J Arid Agric* 8: 8–13. https://doi.org/10.25081/jaa.2022.v8.7430
147. Zhou W, He Y, Liu F, et al. (2021) Carboxymethyl chitosan-pullulan edible films enriched with galangal essential oil: Characterization and application in mango preservation. *Carbohydr Polym* 256: 117579. https://doi.org/10.1016/j.carbpol.2020.117579
148. Kubra IR, Rao LJM (2012) Effect of microwave drying on the phytochemical composition of volatiles of ginger. *Int J Food Sci Technol* 47: 53–60. https://doi.org/10.1111/j.1365-2621.2011.02806.x
149. Rao K, Ch B, Narasu LM, et al. (2010) Antibacterial activity of *Alpinia galanga* (L) Willd crude extracts. *Appl Biochem Biotechnol* 162: 871–884. https://doi.org/10.1007/s12010-009-8900-9
150. Veerasophon J, Sripalakit P, Saraphanchotiwitthaya A (2020) Formulation of anti-acne concealer containing cinnamon oil with antimicrobial activity against *Propionibacterium acnes*. *J Adv Pharm Technol Res* 11: 53–58. https://doi.org/10.4103/japtr.JAPTR_1_20
151. Santos GKN, Dutra KA, Barros RA, et al. (2012) Essential oils from *Alpinia purpurata* (Zingiberaceae): Chemical composition, oviposition deterrence, larvicidal and antibacterial activity. *Ind Crops Prod* 40: 254–260. https://doi.org/10.1016/j.indcrop.2012.03.020
152. Ravichandra V, Hanumantharayappa B, Papasani V (2014) Evaluation of cardio protective activity of galangin against doxorubicin induced cardiomyopathy. *Int J Pharm Pharm Sci* 6: 86–90.
153. Lahlou S, Interaminense LFL, Leal-Cardoso JH, et al. (2003) Antihypertensive effects of the essential oil of *Alpinia zerumbet* and its main constituent, terpinen-4-ol, in DOCA-salt hypertensive conscious rats. *Fundam Clin Pharmacol* 17: 323–330. https://doi.org/10.1046/j.1472-8206.2003.00150.x

154. Lahlou S, Galindo CAB, Leal-Cardoso JH, et al. (2002) Cardiovascular effects of the essential oil of *Alpinia zerumbet* leaves and its main constituent, terpinen-4-ol, in rats: role of the autonomic nervous system. *Planta Med* 68: 1097–1102. https://doi.org/10.1055/s-2002-36336
155. Rocha DG, Holanda TM, Braz HLB, et al. (2023) Vasorelaxant effect of *Alpinia zerumbet*'s essential oil on rat resistance artery involves blocking of calcium mobilization. *Fitoterapia* 169: 105623. https://doi.org/10.1016/j.fitote.2023.105623
156. Pereira PS, Maia AJ, Duarte AE, et al. (2018) Cytotoxic and anti-kinetoplastid potential of the essential oil of *Alpinia speciosa* K. Schum. *Food Chem Toxicol* 119: 387–391. https://doi.org/10.1016/j.fct.2018.01.024
157. Yustica FK, Widiastuti NI, Sapitri N, et al. (2019) Essential oils from *Alpinia purpurata* (Zingiberaceae): Chemical composition and Formulation of antiacne cream. *Indones J Chem Res* 4: 14–21. https://doi.org/10.20885/ijcr.vol4.iss1.art3
158. Khumpirapang N, von Gersdorff Jørgensen L, Müllertz A, et al. (2021) Formulation optimization, anesthetic activity, skin permeation, and transportation pathway of *Alpinia galanga* oil SNEDDS in zebrafish (Danio rerio). *Eur J Pharm Biopharm* 165: 193–202. https://doi.org/10.1016/j.ejpb.2021.04.022
159. Wongphan P, Nampanya P, Chakpha W, et al. (2023) Lesser galangal (*Alpinia officinarum* Hance) essential oil incorporated biodegradable PLA/PBS films as shelf-life extension packaging of cooked rice. *Food Packag Shelf Life* 37: 101077. https://doi.org/10.1016/j.fpsl.2023.101077
160. Xu J, Jiang Z, Peng J, et al. (2023) Fabrication of a protein-dextran conjugates formed oral nanoemulsion and its application to deliver the essential oil from *Alpinia zerumbet* Fructus. *Int J Biol Macromol* 249: 125918. https://doi.org/10.1016/j.ijbiomac.2023.125918
161. Liang W, Ge X, Lin Q, et al. (2024) pH-responsive liposomes for controlled release of *Alpinia galanga* essential oil: Investigating characteristics, stability, control release behavior, and functionality. *Ind Crops Prod* 209: 117978. https://doi.org/10.1016/j.indcrop.2023.117978
162. Damayanti R, Batubara I, Suparto IH (2015) Essential oil of red galangal (*Alpinia galanga* (L) Willd) rhizomes as slimming aromatherapy. *Int J Pharma Bio Sci* 6: 283–289.
163. Nayaka NMDMW, Swari NLP, Yuda PESK, et al. (2022) Essential oil of *Alpinia galanga*: Effect of aromatherapy inhalation in mice and physicochemical characterization. *J Ilm Medicam* 8: 87–92. https://doi.org/10.36733/medicamento.v8i2.3791
164. Daning DRA, Yusiati LM, Hanim C, et al. (2022) Dietary supplementation of galangal (*Alpinia galangal*) essential oil affects rumen fermentation pattern. *Adv Anim Vet Sci* 10: 323–334. https://doi.org/10.17582/journal.aavs/2022/10.2.323.334
165. Daning DRA, Widyobroto BP, Yusiati LM, et al. (2022) Effect of galangal (*Alpinia galanga*) essential oil supplementation on milk production, composition, and characteristics of fatty acids in dairy cows. *Adv Anim Vet Sci* 10: 192–202. https://doi.org/10.17582/journal.aavs/2022/10.1.192.202
166. Khumpirapang N, Chaichit S, Jiranusornkul S, et al. (2018) In vivo anesthetic effect and mechanism of action of active compounds from *Alpinia galanga* oil on *Cyprinus carpio* (koi carp). *Aquaculture* 496: 176–184. https://doi.org/10.1016/j.aquaculture.2018.07.017
167. Zhou W, He Y, Liu F, et al. (2021) Carboxymethyl chitosan-pullulan edible films enriched with galangal essential oil: Characterization and application in mango preservation. *Carbohydr Polym* 256: 117579. https://doi.org/10.1016/j.carbpol.2020.117579

168. Dong J, Zhu X min, Wu F ye, et al. (2020) Development of galangal essential oil-based microemulsion gel for transdermal delivery of flurbiprofen: simultaneous permeability evaluation of flurbiprofen and 1,8-cineole. *Drug Dev Ind Pharm* 46: 91–100. https://doi.org/10.1080/03639045.2019.1706548
169. Wongphan P, Nampanya P, Chakpha W, et al. (2023) Lesser galangal (*Alpinia officinarum* Hance) essential oil incorporated biodegradable PLA/PBS films as shelf-life extension packaging of cooked rice. *Food Packag Shelf Life* 37: 101077. https://doi.org/10.1016/j.fpsl.2023.101077
170. de Lira CS, Pontual EV, de Albuquerque LP, et al. (2015) Evaluation of the toxicity of essential oil from *Alpinia purpurata* inflorescences to *Sitophilus zeamais* (maize weevil). *Crop Prot* 71: 95–100. https://doi.org/10.1016/j.cropro.2015.02.004
171. Api AM, Bartlett A, Belsito D, et al. (2024) Update to RIFM fragrance ingredient safety assessment, eucalyptol, CAS Registry Number 470-82-6. *Food Chem Toxicol* 183: 114439. https://doi.org/10.1016/j.fct.2024.114439
172. Rocha DG, Holanda TM, Braz HLB, et al. (2023) Vasorelaxant effect of *Alpinia zerumbet*'s essential oil on rat resistance artery involves blocking of calcium mobilization. *Fitoterapia* 169: 105623. https://doi.org/10.1016/j.fitote.2023.105623
173. Zhou W, Sun Y, Zou L, et al. (2021) Effect of galangal essential oil emulsion on quality attributes of cloudy pineapple juice. *Front Nutr* 8: 1–11. https://doi.org/10.3389/fnut.2021.751405
174. Podshivalov AV, Bronnikov S, Zuev VV, et al. (2013) Synthesis and characterization of polyurethane-urea microcapsules containing galangal essential oil: statistical analysis of encapsulation. *J Microencapsul* 30: 198–203. https://doi.org/10.3109/02652048.2012.735261
175. Okonogi S, Chaiyana W (2012) Enhancement of anti-cholinesterase activity of *Zingiber cassumunar* essential oil using a microemulsion technique. *Drug Discov Ther* 6: 249–255. https://doi.org/10.5582/ddt.2012.v6.5.249
176. Xu J, Jiang Z, Peng J, et al. (2023) Fabrication of a protein-dextran conjugates formed oral nanoemulsion and its application to deliver the essential oil from *Alpinia zerumbet* Fructus. *Int J Biol Macromol* 249: 125918. https://doi.org/10.1016/j.ijbiomac.2023.125918