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Inhalt

1 Abstract

Essential oils also known as volatile oils can be used in many different fields, like pharmaceuticals, food flavoring and perfumery. Their spectrum of biological activities is very huge, such as antiviral, antibacterial, antifungal, antitumoral, analgesic, sedative, expectorant, antispasmodic, stimulant to skin-regenerative, etc.

The present work provides a detailed insight into the biological, chemical, and pharmacological profile of selected essential oils extracted from the rhizome of various plants: *Alpinia officinarum*, *Acorus calamus, Curcuma longa, Homalomena aromatica, Curcuma amada, Zingiber officinale, Kaempferia galanga* and *Cyperus rotundus*. The listed plants were chosen because of their diversity in activities and usage. There further should be a mix of very well-known and researched plans such as *Zingiber officinale, Curcuma longa*, *Acorus calamus* on the one hand and less researched ones such as *Homalomena aromatica*, *Curcuma amada* on the other hand, based on the number of studies that were found in the literature, using Google Scholar and PubMed.

2 Zusammenfassung

Ätherische Öle können in vielen verschiedenen Bereichen eingesetzt werden, z. B. in der Pharmazie, in der Aromatisierung von Lebensmitteln und in der Parfümerie. Ihr biologisches Wirkungsspektrum ist sehr groß, z. B. antiviral, antibakteriell, antimykotisch, analgetisch, sedierend, schleimlösend, krampflösend, stimulierend, hautregenerierend usw.

Die vorliegende Arbeit gibt einen detaillierten Einblick in das biologische, chemische und pharmakologische Profil ausgewählter ätherischer Öle, die aus dem Rhizom verschiedener Pflanzen gewonnen werden: *Alpinia officinarum, Acorus calamus, Curcuma longa, Homalomena aromatica, Curcuma amada, Zingiber officinale, Kaempferia galanga* und *Cyperus rotundus.* Die aufgelisteten Pflanzen wurden wegen ihrer Vielfalt an Aktivitäten und Verwendungsmöglichkeiten ausgewählt. Außerdem sollte eine Mischung sehr bekannter und erforschter Pflanzen wie *Zingiber officinale*, *Curcuma longa*, *Acorus calamus* und weniger erforschter wie *Homalomena aromatica, Curcuma amada* beschrieben werden, basierend auf der Anzahl der Studien, die in der Literatur mittels Google Scholar und PubMed gefunden wurden.

3 Essential oils

Essential oils are also known as volatile oils. The term essential oil derives from the drug named „Quinta essentia “, named by Paracelsus von Hohenheim of Switzerland. [1]

The name essential oils derives from the term essences", meaning volatile. There are many definitions of essential oils. According to the French Agency for Normalization (AFNOR): „The essential oil is the product obtained from a vegetable raw material, either by steam distillation or by mechanical processes from the epicarp of Citrus, or “dry” distillation.” [1] [2]

European Pharmacopoeia defines the essential oils as “odorous product, usually of complex composition, obtained from a botanically defined plant raw material by steam distillation, dry distillation, or a suitable mechanical process without heating They are volatile and colorless at room temperature, generally liquid and have a characteristic odor. Essential oils density is usually less than one with a few exceptions such as vetiver, cinnamon, and sassafras.

Essential oils have very high optical activity and refractive index. They are present in herbs and are also responsible for the different scents of an herb. They are used in aromatherapy, perfumery, in cosmetic industry as well as in treatment of different diseases. These are the reasons why their usage has become very popular in today’s world. [1][3][4]

Essential oils can be obtained in different parts of a herb and their composition may vary depending on climatic condition, the growing phase of plant, the time of harvest but also on which part of plant is being used. Various parts of a plant can contain essential oils:

- Rhizomes: curcuma,coco-grass,lesser galangal etc
- Leaves: eucalyptus, tea tree oil, papermint, savory, pine needles, etc
- Flowers: orange, rose, lavender, jasmine, chamomile, etc
- Fruits: citrus fruits, anise
- Seeds anise star, coriander etc
- Wood and bark: pemou wood, sandalwood, cedarwood. [1][4]

The focus of this overview lies on essential oils from rhizomes and their biological activities.

3.1 Chemistry of essential oils

Essential oils are a complex mixture and may contain over 300 different components. The components of Essential oils can be mainly divided into two different chemical classes: more frequent one – terpenes (monoterpenes and sesquiterpene) and phenylpropanoids such as safrole, eugenol etc. When the essential oil contains the phenylpropanoid, usually they responsible for the characteristic odor and taste. [1][2][3] As previously mentioned, most of the components of essential oils belong to the terpenes. Nowadays, over 1,000 components have been identified as terpenes, such as: ketones (piperitone, pulegone), aldehydes (sinensal, safranal), alcohols (nerol, linalool), phenols (menthol, thymol) and esters (cedryl acetate). [1] There are also non-terpenic compounds such as eugenol, cinnamaldehyde, and safrole. Minor compounds of essential oils are very important named as the diterpenes. Even when these compounds are present in small amounts in essential oils, they play an important role in several biological activities. [1][5]

Essential oils show a very large variability concerning their composition (qualitative and quantitative). There are two factors responsible for their variation:

1. Intrinsic factors-related to the plant, environment interaction (climate, soil/ground type, harvest time) 2. Extrinsic factors related to the environment and method of extraction [1]

There are so many factors that determine the composition and the yield of essential oils. Sometimes it is not so easy to separate them from each other, because they influence each other and are interconnected. The geographical origin, the degree of maturity of the herb, genetics and seasonal variations are just some of the important factors. [1][6][7][8].

3.2 Biological activity

Essential oils can be used in many different fields, like pharmaceuticals, food flavoring and perfumery. Their spectrum of biological activities is very big, such as antiviral, antibacterial, antifungal, analgesic, sedative, expectorant, antispasmodic, stimulant to skin-regenerative, etc. The mechanism of antibacterial activity has been studied in detail. One of the most important properties through which these oils act is hydrophobicity. The hydrophobicity allows the essential

oils to be incorporated into the lipids of the cell membrane of bacteria, disrupting the structure and making it more permeable. Essential oils can have one or multiple targets of their activity. Some of them can inhibit the growth of *Salmonella typhimirium* and *Escherichia coli* without dissolving the outer membrane or consuming intracellular ATP. But others, such are carvacrol and thymol probably gain access to the periplasm and deeper areas of the cell. Different studies have come to conclusion that essential oils are more efficient against Gram-positive than against Gram-negative bacteria.[1][9][10]

Antioxidant activity depends on the chemical composition of an essential oil. Secondary metabolites with conjugated double bonds and phenols usually exhibit significant antioxidant activities. The most important antioxidant properties have essential oils of nutmeg, cinnamon clove, basil, parsley, thyme, and oregano. The most active compounds are carvacrol and thymol and their antioxidant activity are related to their phenolic structure which has redox properties and plays an essential part in peroxide decomposition and in neutralizing free radicals. [1][11][12].

Anti-inflammatory activity is reflected in the treatment of some inflammatory diseases such as arthritis, rheumatism, or different allergies. Anti-inflammatory activity was reported in the *Melaleuca alternifolia* essential oils. The mechanism of action is by inhibiting the production of inflammatory mediators or by inhibiting the release of histamine. Therefore, the essential oils represent a new option in the treatment of inflammatory diseases. [1][13][14]

The chemoprotective effect against cancer results from their therapeutic potential, which has drawn the attention of researchers to their potential action against cancer. Essential oils would act in the prevention of cancer. The target organ where the mechanism of action takes place is the liver. This process goes through two phases. Phase 1 involves chemical reactions such as oxidation, reduction, and hydrolysis. Phase 2 involves reactions that chemically convert the drug or phase 1 metabolites into compounds soluble enough to be excreted in the urine. [1][15][16][17][18]

4 Selected rhizome-essential oils

4.1. Alpinia officinarum

4.1.1 General

Alpinia officinarum Hance (synonymously called "Gaoliangjiang" in Chinese) belongs to the family of *Zingiberaceae*. This perennial rhizomatous herbal plant can be found in India, China, and Southeast Asia. [19] The plant is 0.7-1.2 m tall; the leaves are lanceolate, glabrous and between 29-40 cm long. The color of the rhizome is dark red or cinnamon brown. [20] [21] The rhizome is similar in shape to ginger. [19] Its odor is described as aromatic, the taste pungent, hot, and spicy. [21]

Figure 1: *Alpinia officinarum Hance Zingiberaceae* [21]

4.1.2 Composition of essential oils

According to the following study, the main components of essential oils from the rhizome of *A. officinarum* according to GC-MS analysis are 1,8-cineol with the highest concentration 28.11%, followed by α-terpineol with 9.17%, γ-muurolene with 7.88%, α-farnesene with 5.73% and the concentration of the rest compounds was below 5%: caryophyllene, α-bergamotene, γ-gurjunene, β-pinene, camphene, α-pinene. Also, the percentage of chemical components depends on the geographical location and the phase of growth of plant. (Table 1) [20]

4.1.3 Use and scientific investigations

A. officinarum essential oil extracted from rhizome, has been shown to have anti-inflammatory, antioxidant, cytotoxic, antiviral, and antimicrobial activities. [22] One of the main compounds from *A. officinarum* rhizome is 1,8-cineole. [23][24] According to the report, 1,8-cineole lowers the proinflammatory cytokines such as TNF-α, IL-1β, and IL-6 in amyloid beta-treated cells and decreases the expression of NOS-2, COX-2 and NF-κB,thus enabling the treatment of neuroinflammation. [25] According to another study, 1,8-cineole also has an effective protection against H1N1 influenza A virus infection in mice by inhibiting early recrudescence of leukocytes in the lungs and suppressing excessive innate inflammatory response. [26] In addition, 1,8-cineol is also used to treat sinusitis, chronic rhinitis, asthma, and bronchitis. [19] [25]

Table 1: Composition of the essential oil of *A. officinarum* in percent. [20]

GC peak number	Retention time	Component	Relative percentage (%)
1	6.85	α-Pinene	1.65
2	7.275	Camphene	1.89
3	8.067	β-Pinece	1.98
4	9.592	Limonene	1.75
5	9.667	Eucalyptol	28.11
6	10.492	γ-Terpinene	0.28
7	11.692	Linalool	0.30
8	13.092	D(+)-Camphor	2.29
9	13.742	Isoborneol	0.67
10	14.067	(+/-)-Terpinen-4-ol	2.25
11	14.450	α-Terpineol	9.17
12	15.308	Fenchyl acetate	0.54
13	15.942	Benzylacetone	0.21
14	16.717	(E)-Cinnamaldehyde	1.29
15	17.175	Isobornyl formate	0.18
16	18.308	Isobutyl benzoate	0.22
17	19.567	Ylangene	0.41
18	20.083	2-Phenylethyl 2-bromopropanoate	0.80
19	20.858	Caryophyllene	4.66
20	21.192	α-Bergamotene	4.18
21	21.292	α-Guaiene	0.67
22	21.642	(E)-beta-Farnesene	0.55
23	21.725	α-Caryophyllene	1.81
24	22.117	Bicyclo [2.2.1] heptane, 2-cyclopropylidene-1, 7, 7-trimethyl	0.21
25	22.258	Guaiene	0.83
26	22.358	Germacrene D	0.25
27	22.442	Phenethyl 2-methylbutyrate	0.53
28	22.558	Eudesma-4(14),11-diene	1.92
29	22.775	γ-Gurjunene	3.63
30	22.925	α-Farnesene	5.73
31	23.000	r-Himachalene	2.19
32	23.208	γ-Muurolene	7.88
33	23.400	δ-Cadinene	1.97
34	23.750	(-)-α- Gurjunene	1.08
35	23.900	β-Panasinsene	1.19
36	24.283	γ- Elemene	0.93
37	24.983	Tricyclo[6.3.0.0(2,4)]undec-8-ene, 3,3,7,11-tetramethyl-	0.41
38	25.058	2,3,3-Trimethyloctane	0.23
39	25.617	Cubenol	0.60
40	26.008	Viridiflorol	0.23
41	26.192	T-cadinol	0.33
42	26.525	Epiglobulol	1.04
43	26.792	(Z,E)-α-Farnesene	0.35
44	27.317	2,8-Dimethy-undecane	0.21
45	27.475	α-Bulnesene	0.43
46	27.750	Z-α-Trans-Bergamotol	0.44
		Total identified	98.47

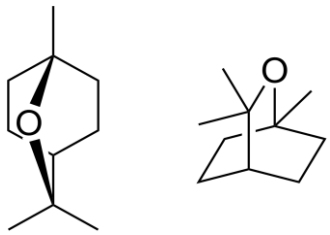

Figure 2: Chemical structure of 1,8-cineol [27]

Other uses of *A. officinarum* rhizome would be as a substitute for antibiotics, as a disinfectant, and as food seasonings. [28] A study has investigated the anti-lung cancer activity of the essential oil from *A. officinarum*. The essential oil was extracted by hydro distillation and identification of its components was done by GC-MS analysis. The experiment has been conducted in vitro and it has shown that the essential oil of *A. officinarum* inhibits the proliferation of lung cancer cells and causes apoptosis of lung cancer cells. Lung cancer is the leading cause of cancer-related deaths worldwide. Therefore, the essential oil from Alpinia officinarum could be a potential candidate for the elimination of lung cancer with a not so many side effects. [29]

4.2. Acorus Calamus L.

4.2.1 General

Acorus calamus L. commonly known as “Sweet Flag” belongs to *Acoraceae* family. It is a semi-aquatic perennial plant found in moist, swamp places especially on the shores of lakes and creeks in India, Iran, Myanmar, southern China, Europe, and North America. It has infinitely branched rhizomes cylindrical up to 20 cm long and 2 cm in diameter. The color ranges from dark brown to orange - brown. They break easily with a short corky fracture and have a whitish, spongy interior. The plants very rarely bloom and fruit, but when they do, the flowers are 3 to 8 cm long, cylindrical, greenish-brown and with a multitude of round spikes. The smell is aromatic and pleasant, the taste is bitter and pungent. The Persian variety has a darker color when broken, and a stronger odor. [21] [30]

Figure 3: *Acorus calamus* [21]

4.2.2 Composition of essential oils

The essential oil extracted from the dry rhizome of *A. calamus* by hydro-distillation process. GC-MS analysis of the essential oil of the rhizome of *A. calamus* showed biologically active components: β-asarone (82.42%) was the most important component and calarene (2.41%), euasarone (1.92%), 2-methoxy-3-allylphenol (1.91 %), methyl-isoeugenol (1.51 %) and di-epicedrene-1-oxide (1.51 %) were found as minor components (Table 2). The chemical components of the essential oil differ depending on the geographical location and on the growth phase which means if the same plant is put in different geographical location, it will mostly end up with different amount of essential oil in percentage. For example, the rhizome from Lithuania had acorenone (20.86%), isocalamendiol (12.8%), and β-cedrene (1.7%). [31]

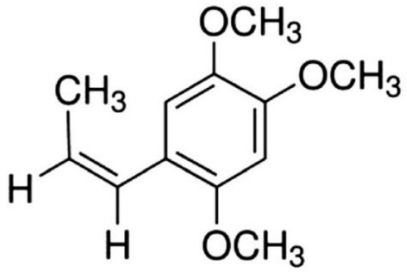

Figure 4: Chemical structure of beta asaron [32]

Table 2: Essential oils from *A. calamus* Rhizome [31]

No.	Compounds	RT(Min)	Area (%)	KI*	KI**
1	Methyl 2-methylbutyrate	03.22	0.04	1007	1006
2	Ocimene	05.77	0.18	1037	1034
3	Camphene	06.24	0.02	1057	1058
4	L-Linalool	06.49	0.13	1096	1097
5	Terpineol	07.05	0.09	1133	1132
6	α-Citronellol	08.13	0.04	1225	1227
7	Nerol	09.01	0.05	1229	1230
8	Linalyl acetate	10.39	0.03	1257	1259
9	Neric acid	10.40	0.04	1299	1294
10	10-Undecenal	10.97	0.02	1299	1296
11	2-Methoxy-3-allylphenol	11.95	1.91	1362	1366
12	Calarene	12.18	2.41	1433	1437
13	α-Maaliene	13.20	0.12	1442	1441
14	Methyl isoeugenol	13.67	1.51	1453	1452
15	Culcatol	14.16	0.03	1460	1461
16	Germacrene-D	14.85	0.14	1481	1480
17	Epiglobulol	15.35	0.14	1548	1549
18	Euasarone	15.64	1.92	1574	1574
19	Spathulenol	15.79	0.12	1578	1580
20	β-Asarone	16.53	82.42	1617	1618
21	Dieoicedren-1-oxide	16.89	1.51	1620	1622
22	Isolongifolenone	16.89	0.13	1627	1629
23	Acorenone	18.51	0.45	1692	1690
24	*iso*-Calamendiol	18.93	0.73	2462	2460
25	Paroxetine	20.82	0.27	2673	2672
	Identified		94.45		
	Unidentified		5.55		

RT = Retention time (min), Area (%) = Peak volume percentage of compounds, KI*= Kovats index literature, KI*= Kovats index of essential oil of *A. Calamus*

4.2.3 Use and scientific investigations

Rhizomes from *A. calamus* are traditionally used medicinally for various conditions such as fever, asthma, bronchitis, cough and especially for poor digestive functions such as flatulence. Its essential oils have shown antioxidative, antimicrobial, antifungal, and insecticidal activity. [30] A study has shown that the essential oil has an enormous inhibitory effect against the growth of fungi and as well as bacteria, for which it can be used to prevent the spoilage of food. The method used to check the antibacterial and antifungal activity was the disk diffusion. It is less expensive, and a standard method used when measuring the antibacterial and antifungal activity. The essential oil concentrations were prepared at 50-500 µg/mL in methanol. Tests were performed three times to reduce the experimental mistake. The evaluation of the antibacterial and antifungal activities was based by measuring the zone of inhibition on the plates. Mueller and Hinton Broth (MHB) from bacterial broth was used for bacterial culture preparation (37°C, 24 h) and Potato Dextrose Broth (PDB) for fungal culture (28°C, 48 h). The following bacteria were used for antibacterial activity testing: *Staphylococcus aureus*, *Bacillus subtilis*, *Bacillus cereus* and *Salmonella tymphimurium*. And the for the antifungal activity following fungi: *Aspergillus niger*, *Aspergillus fumigatus, Candida albicans* and *Saccharomyces cerevisiae*. Antibiotic ciprofloxacin was used as standard for bacterial strains and antifungal fluconazole for fungal strains. The highest zone of inhibition at fungal strains was observed in *A. fumiges* (16 mm diameter) which is even lower than that of the standard (fluconazole, 18 mm diameter) and lowest in *S. cerevisiae* (12 mm diameter). (Table 3) Among bacterial strains, the zone of highest inhibition was found in *B. subtilis* (12 mm diameter) which is also lower than that from standard ciprofloxacin (18 mm diameter) and the lowest in *B. cereus* (8 mm diameter) at 500 µg/mL concentration. (Table 4) [31] Another study has shown low inhibitory activity against *S. aureus* (9.2 diameter) at 10 µg/mL. Also, according to this study, Acorus calamus essential oil (β-asarone) had stronger antifungal activity than antibacterial activity. [33]

Most of the studies have shown that the essential oil from *A. calamus* exhibited the antibacterial activity. [30] [34] [35] [36]

Table 3: Zone of inhibitions of essential oil (*A. calamus*) and fluconazole against different fungal strains [31]

Fungal strains	Concentrations (µg/mL) 50	100	250	500	Fluconazole 10 µg/disc
	Zone of inhibition (mm ± SD)				
A. fumigates	14±0.013	14±0.016	16±0.012	16±0.011	18±0.012
A. niger	7±0.011	10±0.019	13±0.018	15±0.017	14±0.017
S. cerevisiae	-	9±0.013	11±0.012	12±0.012	16±0.013
C. albicans	6±0.009	9±0.017	11±0.016	15±0.014	23±0.014

Table 4: Zone of inhibitions of essential oil (*A. calamus*) and ciprofloxacin against bacterial strains [31]

Bacterial strains	Concentrations (µg/mL) 50	100	250	500	Ciprofloxacin 5 µg/disc
	Zone of inhibition (mm ± SD)				
S. aureus	5±0.012	8±0.017	8±0.012	9±0.015	21±0.012
B. subtilis	7±0.020	9±0.011	10±0.015	12±0.012	18±0.017
B. cereus	-	6±0.013	7±0.019	8±0.017	17±0.013
S. typhimurium	-	-	8±0.013	10±0.015	23±0.015

4.3 Curcuma longa L.

4.3.1 General

Curcuma longa L. belongs to the *Zingiberaceae* family. It is a perennial aromatic herb, between 0.6-1 m tall, widely cultivated in the tropical regions of Asia. The shape of its leaves is oblong or elliptic, shortly pointed, narrow at base, glabrous on both sides, 45 cm long and 18 cm wide. The flowers are pale yellow. The color of the rhizome is deep orange, for that reason the rhizome is widely used to add color and taste to various foods. Cooked and dried rhizome is marketed as spice and mostly used for flatulence, dyspepsia, intermittent fever. The powder of *C. longa* is

called turmeric, and ancient texts attribute aromatic, stimulating and carminative properties to it as well usage for stress, dyspepsia, and mood disorders. With plant growth the concentration of essential oil in the rhizome increases whereas it decreases during long storage. The essential oil (4.5-6%) consists of turmerone with 58% which is the major component as well as zingiberene with 20% and small percentage of sesquiterpene phellandrene, and borneol and alcohols. The essential oil of *C. longa* is believed to have antibacterial, anti-fungal, anti-tumor, hypolipidemic, anti-arthritic and anti-thrombotic activities. [21] [36] [37][38][39]

Figure 5: *Curcuma longa* [21]

4.3.2 Chemistry of essential oil

The essential oil was extracted from dry and from fresh rhizome. The chemical components were analyzed by GC-MS. The following results were obtained, total of 38 chemical components were identified in fresh rhizome oil as well as in dry rhizome oil. The major chemical components from fresh rhizome were ar-turmerone with the highest concentration 24.4%, followed by alpha-tumerone with concentration of 20.5% and beta-turmerone with 11.1%, all other components were below 10% such as: beta-caryophyllene, beta-sesquiphellandrene, terpinolene and alpha-zingiberene. On the other hand, major components from dry rhizome were ar-turmerone with the highest concentration of 21.4%, all other components were below 10% such as: alpha-santalene, ar-curcumene, santalenone, beta sesquiphellandrene and beta-bisabolene. (Table 5). There are a

few differences when comparing essential oils from dry and fresh rhizomes. The concentration of ar-turmerone was a little bit higher in fresh rhizome, also major difference was alpha-turmerone which concentration was much higher in fresh rhizome as well as beta-turmerone. [40] Previous studies showed very similar results concerning to major chemical compounds from rhizome such as ar-turmerone, alpha-tumerone and beta-tumerone. [38] [41] [42] [43]

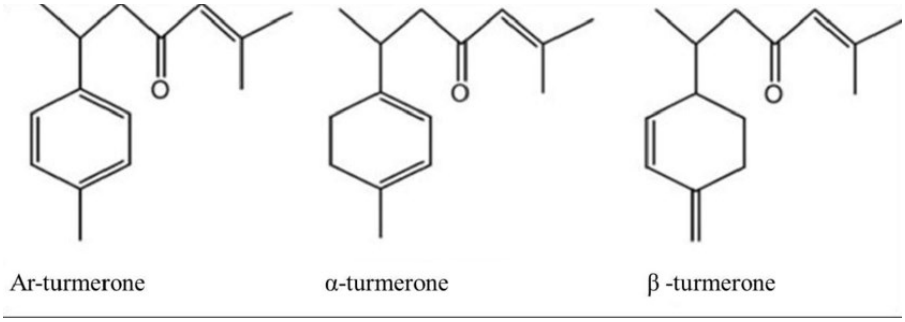

Figure 6: Chemical structure of major components of *C. longa* essential oil [44]

4.3.3 Use and scientific investigations

C. longa is a very well-known plant, mainly because of its rhizome and its numerous effects such as antimicrobial, antiviral, anti-inflammatory, antioxidant, and anti-cancer properties. [45] [38][39] [46][47] In a study, the antifungal effect on different fungi such as *Aspergillus flavus*, *Cladosporium cladosporioides* and *Penicillium brevicompactum* was tested. Two natural biocides such as *C. longa* essential oil obtained from dry rhizome and Cuban propolis were used, as well as two synthetic antiseptic detergents and Tween 20 at following concentration (0, 0.001, 0.1 and 1.0%). There were two response variables: the superficial growth of mycelium in cm and sporulation inhibition in %. Additionally, to total radial growth inhibition (IRG) and partial sporulation inhibition (PIS), the minimum inhibitory concentration (MIC) of essential oil was determined. Diameter of colony from *A. flavus* decreased inversely proportional to the concentrations, and at 1% v/v it reduced the diameter more than threefold, which was selected as the MIC because it caused IRG and PIS. Three strains were observed for their inhibition of spores in a directly proportional relationship to the concentrations of four biocides. [48]

Table 5: Chemical compounds of essential oil from fresh (FC1) and dry (DC1) rhizomes from *C. longa* [40]

Compound	FC1 (%)	DC1 (%)	Identification[a]
alpha-Pinene	Trace	Trace	MS, RI, co-GC
Sabinene	Trace	Trace	MS, RI, co-GC
beta-Pinene	Trace	Trace	MS, RI, co-GC
Myrcene	0.1	Trace	MS, RI, co-GC
alpha-Phellandrene	0.1	–	MS, RI, co-GC
3-Carene	0.1	–	MS, RI, co-GC
alpha-Terpinene	0.1	–	MS, RI, co-GC
p-Cymene	0.3	0.1	MS, RI, co-GC
Limonene	0.1	Trace	MS, RI, co-GC
1,8-Cineole	0.4	0.1	MS, RI, co-GC
Terpinolene	2.7	Trace	MS, RI, co-GC
p-Cymen-8-ol	0.9	Trace	MS, RI, co-GC
beta-Elemene	–	0.1	MS, RI
cis-alpha-Bergamotene	0.1	0.2	MS, RI
beta-Caryophyllene	3.1	0.5	MS, RI
alpha-Santalene	0.4	7.2	MS, RI
trans-alpha-Bergamotene	0.1	1.6	MS, RI
epi-beta-Santalene	Trace	1.0	MS, RI
alpha-Humulene	0.6	–	MS, RI
trans-beta-Farnesene	0.2	0.8	MS, RI
Sesquisabinene	0.2	1.6	MS, RI
ar-Curcumene	1.6	6.6	MS, RI
alpha-Zingiberene	2.5	0.8	MS, RI
(E,E)-alpha-Farnesene	Trace	0.1	MS, RI
beta-Bisabolene	0.8	4.1	MS, RI
Sesquicineole	–	0.1	MS, RI
beta-Sesquiphellandrene	2.9	4.2	MS, RI
trans-gamma-Bisabolene	0.1	0.9	MS, RI
cis-Sesquisabinene hydrate	0.3	0.6	MS, RI
trans-Nerolidol	0.5	0.3	MS, RI
Santalenone	1.1	5.6	MS, RI
ar-Turmerol	0.4	0.9	MS, RI
cis-beta-Elemenone	–	0.1	MS, RI
Dihydro-ar-turmerone	0.4	0.9	MS, RI
ar-Turmerone	24.4	21.4	MS, RI
alpha-Turmerone	20.5	0.6	MS (Ref. 1)
beta-Bisabolol	–	3.0	MS, RI
Germacrone	1.0	2.6	MS, RI
beta-Turmerone	11.1	4.3	MS (Ref. 1)
Curcuphenol	0.2	–	MS, RI
6R, 7R-Bisabolone	1.7	0.8	MS, RI
trans-alpha-Atlantone	0.9	2.6	MS, RI
Total	79.9%	73.1%	

Trace: <0.05%; The percentages are the average of three runs and were determined by electronic integration measurements with a selective mass detector

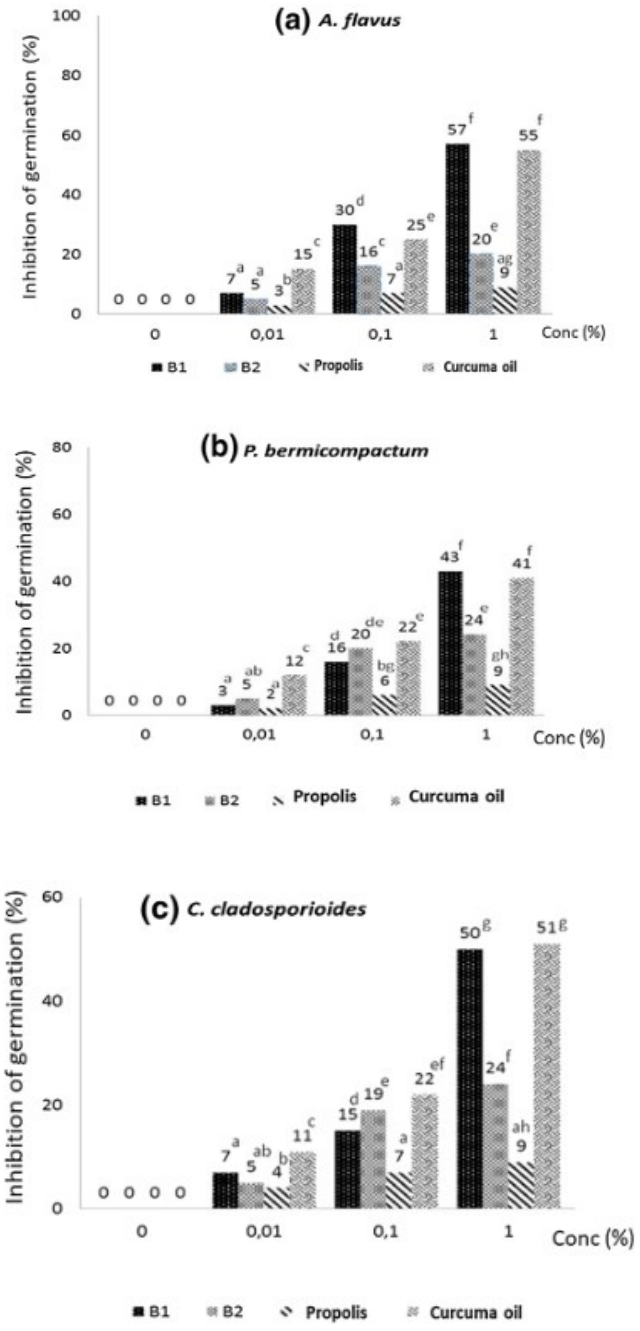

Figure 7: The effect of Deconex antiseptic detergent (B1), Tween 20 (B2) surfactant, Cuban propolis and *C. longa* essential oil in inhibition of germination.

t = 24h. **a.** A. flavus, **b.** *P. brevicompactum* and **c.** *C. cladosporioides*. Different letters indicate statistically significant differences ($p \leq 0.05$) for n = 96 and for Fisher's LSD [48]

All spores were inhibited that had similar values to the antiseptic detergent, by essential oil at a MIC (1%) between 41 and 55%. *A. flavus*, *P. brevicompactum*, and *C. cladosporioides* and germination inhibition showed a directly proportional relationship, i.e., at higher concentration of biocide the spores germinated less. The experiment revealed that the commercial detergent had the stronger efficacy when compared to the Tween 20 surfactant, on the other hand propolis had the weakest inhibitory effect (Figure 7). For all biocides, at 1% v/v, the impairment of germination of conidia of fungal species observed in declining order: *A. flavus, P. brevicompactum* and *C. cladosporioides*. This could be due to the size of their spores because the spores of *C. cladosporioides* are twice as large as those of the other two. This led the authors to conclude that *C. longa* essential oil can be used as a highly effective antifungal agent. [48]

In another study, *C. longa* essential oil was evaluated for its antibacterial activity. The following bacteria were used: *E. coli*, *S. aureus*, *S. epidermidis* and *P. aeruginosa* by the disc diffusion and microdilution test. The Minimum Inhibitory Concentration (MIC) of the essential oil was determined by a broth microdilution method. The concentrations of essential oils that was added to the suspensions varied from 5.5µL/mL to 111.1µL/mL. Each test was performed in triplicate. [47]

Table 6: Growth inhibition zone (mm) and MIC (Minimum Inhibitory Concentration) (µL/mL) of *C. longa* essential oil from rhizome against different bacteria [47]

Strains tested	Growth inhibition (mm)	MIC (µl/mL)
Staphylococcus aureus	8.3 ± 0.2	38.8
Staphylococcus epidermidis	9.0 ± 0.1	50.0
Escherichia coli	8.0 ± 0.3	44.4
Pseudomonas aureuginosa	9.3 ± 0.2	27.7

Looking at the results from microdilution test (Table 6), essential oil from *C. longa* has proven to be effective in inhibiting all tested bacteria. It follows that *C. longa* essential oil can be used as an antibacterial agent. [47]

According to another study, the essential oil of *C. longa* was effective not only against the four strains of bacteria mentioned above, but also against *Bacillus subtilis*, *B. coagulans*, and *B.*

cereus. [49] All these studies lead the investigators to conclude that *C. longa* essential oil can be used as an antibacterial agent.

According to a further study, *C. longa* essential oil can also reduce skin photoaging in a UVB-irradiated nude mouse model. Authors believe that for the anti-aging effect of the *C. longa* essential oil, ar-turmerone, curlone, and β-turmeron play a major part. Based on the results, *C. longa* essential oil could be used in anti-aging creams and cosmetics although further studies are needed. [38]

4.4 Homalomena aromatica Schott

4.4.1 General

Figure 8: *Homalomena aromatica Schott* [50]

Homalomena aromatica Schott syn. *Calla aromatica* belongs to the *Araceae* family. It is a perennial shade loving herb with large aromatic rhizomes with bittersweet-taste. The leaves are

18-34 cm long and 14-23 cm wide. Flowers are mostly unisex, fruits are berries with seeds who are small, egg-shaped, and proteinaceous. It is commonly found in Assam and Himalayan regions of India. [51][52][53][54]

4.4.2 Chemistry of essential oils

The essential oil was extracted from *H. aromatica* and analyzed by GC-MC. The following results were obtained. Major components were linalool with 62.1%, followed by terpinen-4-ol with 17.2%, α-Terpineol 2.4%, nerol 1.4% and other minor components. (Table 7) [53]

The comparative analyses of chemical components of *H. aromatica* essential oil by previous reports are shown in Table 8. In all listed studies the major components of essential oil were linalool followed by terpene-4-ol. [55] GC analysis of essential oil from *H. aromatica* with the main components and their chemical structures can be found in Figure 9. [52]

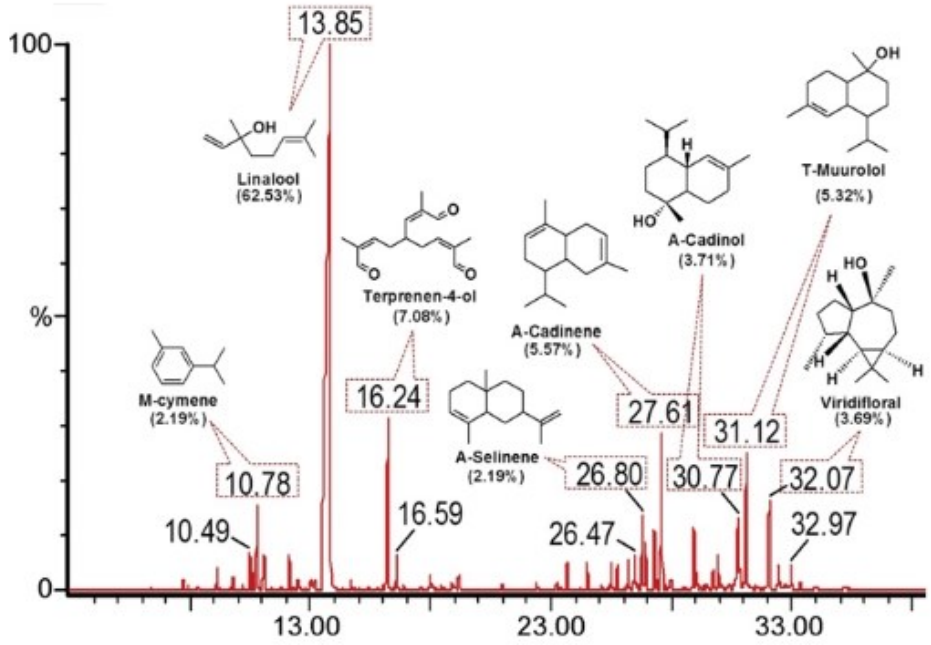

Figure 9: GC analysis of the essential oil of *H. aromatica* with the main compounds. [52]

Table 7: Chemical composition of essential oil from *H. aromatica*. [53]

Compounds	Percentage
α-Thujene	tr
Sabinene	0.5
β-Pinene	tr
Myrcene	tr
α-Phellandrene	tr
δ-3-Carene	0.5
α-Terpinene	1.0
p-Cymene	0.9
β-Phellandrene	0.3
Limonene	0.6
(*Z*)-β-Ocimene	tr
(*E*)-β-Ocimene	tr
γ-Terpinene	1.9
cis-Linalool oxide	0.2
trans-Linalool oxide	0.3
Terpinolene	0.5
Linalool	62.1
cis-*p*-Menth-2-en,1-ol	tr
trans-*p*-Menth-2-en,1-ol	tr
Cryptone	tr
Terpinen-4-ol	17.2
α-Terpineol	2.4
Eucarvone	0.3
Cuminaldehyde	tr
Nerol	1.4
Piperitone	tr
Geraniol	1.4
Phellandral	0.3
Cuminol	tr
Neryl acetate	tr
δ-Cadinene	tr
α-Selinene	tr
Spathulenol	1.0
Caryophyllene oxide	0.2
T-cadinol	1.0
α-Cadinol	1.5
Oplopanone	0.4
2-Cyclohexen-3-ol,1-one,2-octanoyl	0.4
Oplodiol	tr
Other compounds	3.1

Table 8: Comparison of major compounds of *H. aromatica* essential oil [52]

Sl. No.	Major components (%)		
	Todorova et al. (1988)	Singh et al. (2000)	Present study (2011)
1	Linalool (71.2%)	Linalool (62.1%)	Linalool (62.5%)
2	Terpene-4-ol (4.6%)	Terpinen-4-ol (17.2%)	Terpene-4-ol (7.08%)
3	Linalyl acetate (3.3%)	α-terpineol (2.4%)	δ-cadinene (5.57%)
4	δ-3-carene (1.3%)	γ-terpinene (1.9%)	T-muurolol (5.32%)
5	α-terpineol (1.2%)	α -cadinol (1.5%)	α-cadinol (3.71%)
6		Geraniol (1.4%)	Viridiflorol (3.69%)
7		Nerol (1.4%)	α- selinene (2.19%)
8		α -terpinene (1.0%)	M-cymene (2.19%)
9		Spatulenol (1.0%)	Spatulenol (1.81%)
10		T-cadinol (1.0%)	γ-Muurolene (1.81%)
Total constituents	37	39	55

4.4.3 Use and scientific investigations

The essential oil from the rhizome of *H. aromatica* is known for its medicinal properties such as antibacterial, antifungal, analgesic, anti-inflammatory, sedative, insecticidal and antiseptic. [52][53][55][56]. In the study of Singh and coworkers, insecticidal and antifungal activity were tested. [53] Petriplate method was used to test the antifungal activity. The antifungal activity of essential oil was tested on four fungal strains*: Curvularia pallescens*, *Aspergillus niger*, *Fusarium solani* and *F. graminearum*. Three different concentrations of oil were used (10 µl, 20 µl and 30 µl), and the experiment was repeated three times. The antifungal test results have shown that the oil was 100% effective against *C. pallescens* even at 20 µl and high effective against *A. niger* with 89% at 30 µl and *F. graminearum* with 95% at 30 µl and not so effective against *F. solani* with only 7% at 30 µl (Table 9). [53]

Table 9: Antifungal activity of *H. aromatica* essential oil from rhizome [53]

		% Mycelial zone inhibition[a] at different dose of oil		
S. no.	Fungas	10 µl	20 µl	30 µl
1	*Curvularia pallescens*	70	100	100
2	*Aspergillus niger*	56	78	89
3	*Fusarium solani*	0	0	7
4	*Fusarium graminearum*	50	75	95

Insecticidal activity against white termites was tested in 80-mm petri plates with three different oil doses (3 µl, 6 µl, and 9 µl) for two, five, and seven hours. Blank filter paper disc was used as a control. The experiment was repeated three times. Results ae listed in Table 10. [53]

Table 10: Insecticidal activity of essential oil from *H. aromatica* rhizome against white termites [53]

Dose of oil (µl)	No. of insects taken	% mortality[a] at different exposure periods		
		2 h	5 h	7 h
3	10	90	100	100
6	10	100	100	100
9	10	100	100	100
Control	10	0	0	20

A look at Table 9 shows that the *H. aromatica* essential oil was very toxic to white termites. Even at the smallest dose of 3 µl and the shortest exposure time of two hours, nine out of ten insects were found dead, making this essential oil a great candidate for insecticidal activity. [53]

A further study has demonstrated the efficacy of linalool in terms of antifungal and antibacterial activity. The results showed high efficacy of linalool against two fungal strains (*C. albicans* and *Aspergillus brasiliensis*) and three bacterial strains (*P. aeruginosa, E. coli* and *S. aureus*). [56]

Another study has demonstrated and proved the efficacy of linalool against bacterial and fungal strains including *Prevotella intermedia, Fusobacterium nucleatum vincentii, Fusobacterium nucleatum fusiforme, Fusobacterium nucleatum animalis, Aggregatibacter actinomycetemcomitans* and *Aggregatibacter actinomycetemcomitans*. [57]

In another study, the antibacterial activity of linalool against *Pseudomonas fluorescens* was tested, and it was found that linalool had a significant inhibitory effect. Linalool thus seems to be a candidate for an effective antibacterial and antifungal agent. [58]

4.5 Curcuma amada Roxb.

4.5.1 General

Curcuma amada Roxb. belongs to the *Zingiberaceae* family and is a perennial plant. A synonym for *C. amada* is Amada or "Amahaldi" or "mango ginger" because the aroma of the rhizome resembles mango. This genus includes 80 species that are adapted to grow from sea level to 2000 m above sea level. [59]. It can be found in different parts of the world, mostly grown in India and in the following parts: Gujarat, West Bengal, Uttar Pradesh, Karnataka, Konkan and in the hills of the Western coast of India, but there is not commercial cultivation anywhere in the world. [60]. The bulb has an ovoid shape while the rhizome is large, branched, and yellow on the surface. Many hanging tubers are present, and the leaves are large oblong shape, the underside of the leaves is wrinkled while the upper side is flat. The rhizome is rich in essential oils and has a lot of medical benefits. [59]

Figure 10: *Curcuma amada* [61]

4.5.2 Chemistry of essential oil

According to previous research, it has been found that *C. amada* rhizome contains more than 130 different chemical ingredients, 121 of which have been identified. They were isolated from fresh or dried *C. amada* rhizomes, while in some studies the condition of the rhizome used was not reported. According to this study, steam distillation is the dominant method used to isolate essential oils, while GC-MS are the main tools used to separate and detect mango compounds. [62]

According to the GC-MS analysis of the *C. amada* rhizome essential oil, the main chemical components were the β-myrcene (Figure 11) with concentration of 40%, followed by β-pinene with concentration of 11.78% and ar-curcumene with 10%, all other components were below 10% such as: camphor, α-pinene, perillene, α-terpinol, safrole, α-zingiberene etc. (Table 11) [63]

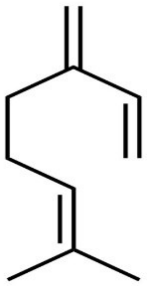

Figure 11: Chemical structure of β-Myrcene [64]

4.5.3 Use and scientific investigations

C. amada is pharmacologically important for several complaints. It has been effective in healing skin allergies, stomach problems as well as high blood cholesterol. If further exhibits antioxidant properties and antibacterial activity. [65] [66] A natural antibacterial compound (difurocumenonol), which was isolated from mango ginger, showed potent antibacterial activity against a wide range of bacteria including both Gram-negative and Gram-positive bacteria such as: *P. aeruginosa*, *Salmonella typhi*, *Klebsiella typhi*, *K. pneumoniae*, *Enterobacter aerogenes*, *Yersinia enterocolitica*, *Micrococcus luteus*, *S. aureus*, *Enterococcus fecalis* etc. [66]

Table 11: Chemical composition of *C. amada* essential oil [63]

S.No.	Constituent	Our findings	Choudhury, Rabha, Kanjilal, and Ghosh (1996)	Srivastava et al. (2001)	Singh, Singh, Lampasona, and Catalan (2003)	Dutt and Tayal (1941)
1	Propanone	–	–	–	0.19	–
2	Tricyclene	–	–	–	t	–
3	α-pinene	1.48	0.9	0.4	0.70	18.0
4	Camphene	0.24	–	1.7	0.18	–
5	Sabinene	–	–	–	t	–
6	β-pinene	11.78	4.9	0.6	4.64	–
7	β-myrcene	40.2	88.6	0.2	80.54	–
8	p-cymene	–	–	–	–	–
9	Limonene/ β-phellandrene	0.27	0.1	0.4	0.13	–
10	1,8-cineole	0.06	0.1	6.0	0.06	–
11	(Z)-β-ocimene	–	2.4	–	0.22	47.2 E&Z
12	(E)-β-ocimene	1.01	–	–	1.88	–
13	(E)-decahydro naphthalene	1.77	–	–	–	–
14	2-nonanone	–	–	0.1	–	–
15	Linalool	–	–	0.4	–	11.2
16	Perillene	1.81	0.4	–	1.47	–
17	(E)-thujone	–	–	–	–	–
18	(E)-sabinol	–	–	–	–	–
19	Camphor	3.21	–	11.2	t	–
20	Isoboneol	–	–	4.5	–	–
21	Borneol	0.12	–	1.3	–	–
22	terpinen-4-ol	–	–	0.2	0.09	–
23	α-trepineol	1.00	–	0.8	–	–
24	linalyl acetate	–	–	–	–	9.1
25	bornyl acetate	–	–	–	–	–
26	Safrole	1.03	–	–	–	9.3
27	δ-elemene	–	–	0.2	–	–
28	α-copaene	–	–	–	0.13	–
29	β-elemene	1.00	–	2.8	–	–
30	β-(E)-caryophyllene	0.75	–	0.2	0.53	–
31	β-gurjunene	–	–	–	0.07	–
32	α-(E)-bergamotene	–	–	0.2	–	–
33	α-humulene	–	–	–	0.05	–
34	ar-curcumene	10.00	–	28.1	–	–
35	β-selinene	–	–	0.6	–	–
36	α-selinene	–	–	0.5	–	–
37	α-zingiberenne	1.2	–	1.4	–	–
38	α-muurolene	–	–	–	0.07	–
39	β-curcumene	–	–	11.2	–	–

S.No.	Constituent	Our findings	Choudhury, Rabha, Kanjilal, and Ghosh (1996)	Srivastava et al. (2001)	Singh, Singh, Lampasona, and Catalan (2003)	Dutt and Tayal (1941)
40	Cubebol	–	–	–	–	–
41	Spathulenol	–	–	0.3	–	–
42	caryophyllene oxide	0.22	–	0.5	0.34	–
43	Curzerenone	0.36	–	7.1	0.14	–
44	α-muurolol	–	–	–	0.04	–
45	β-bisabolol	–	–	0.5	–	–
46	Germacrone	–	–	0.3	–	–
47	Zerumbone	–	–	0.2	–	–
48	Others	22.69	2.6	18.1	8.53	5.2
Total %		77.31	74	81.9	91.47	94.8

Note: t – trace (>0.1%).

The essential oils of *C. amada*, in combination with those of other plant species also showed antifungal activities against fungal pathogens such as *Physalospora tucumanensis*, *Sclerotium rolfsii*, *Helminthosporium sacchari*, *Fusarium moniliforme var. subglutinans* and *Cephalosporium sacchari* in various extracts. [67] Antioxidant properties of raw methanol extracts of *C. amada* rhizomes were evaluated based on the reaction to free radicals with curcumin. As a baseline indicator for the reaction with sulphur-free radicals was the lowering of a clean curcumin sample determined by simple spectrophotometric method. Those results confirmed the potential medicinal use of *C. amada* rhizomes as a food supplement. In the study, the antioxidant activity of various plant parts of *C. amada*, compared to other Curcuma species, was examined with main interest in the leaves and rhizomes. The rhizomes of *C. amada* were relatively less effective as antioxidants than the leaves. [66]

4.6 Zingiber officinale Roscoe

4.6.1 General

Zingiber officinale Roscoe belongs to the family of *Zingiberaceae* and grows in tropical Asia but is also now cultivated in America, Australia, India, China, and Africa. It is a smooth, small, perennial, rhizomatous plant, usually between 0.9 m -1.2 m tall. The leaves are narrow lanceolate, flowers greenish-yellow, small with purple pubescence and yellow spots. The rhizome is thick, ring-shaped, aromatic, yellowish in color. The smell is aromatic and taste spicy. Zingerone and shogaol give the rhizomes the pungency and the essential oil gives the aroma. [21] [68]

Figure 12: *Zingiber officinale* [21]

4.6.2 Chemistry of essential oils

The chemical components of the *Z. officinale* essential oil were identified by the GC-MS analysis. *Z. officinale* essential oil has showed very high content of sesquiterpenes with the concentration of 66.66%, followed by monoterpenes and aliphatic components. Following components were identified: zingiberene with the highest concentration of 46.71%, followed by citronellyl n-butyrate with 19.34%, all other components were below 10% such as: valencene, β-phellandrene, camphene, α-pinene, see the Table 12. [69]

Table 12: Chemical composition of essential oil from *Z. officinale* rhizome (Ghaziabad region) [69]

Components	Kovat's Index	% Area
α-Pinene	937	1.09
Camphene	943	2.53
2-Methyl nonane	964	0.29
Myrcene	975	0.45
α-Phellandrene	987	0.20
3-Octen-2-one	1006	0.63
(+)-α-Limonene	1011	0.82
β-Phellandrene	1015	3.70
α-Terpinolene	1067	0.16
n-Nonenal	1130	0.14
2-Methyl undecane	1164	0.15
3-Methyl butanol	1205	0.54
n-Nonan-2-one	1280	0.11
α-Nagniatene	1317	0.18
α-Cubebene	1348	0.16
δ-Elemene	1345	0.53
p-Menth-1-en-8-ol acetate	1348	0.11
Cyclosativene	1357	0.55
α-Copaene	1375	0.95
n-Undecanol	1381	0.37
Geranyl acetate	1383	0.32
Camphor isomer	1391	0.10
Methyl eugenol	1404	0.68
Bergamotene	1417	0.95
α-Santalene	1419	0.54
Geranyl propionate	1430	0.25
(Z,E)-α-Farnesene	1433	0.10
γ-Elemene	1437	0.41
n-Decanyl acetate	1439	0.39
Neryl acetone	1441	0.79
Allo-Aromadendrene	1455	0.32
Germacrene D	1458	0.82
β-Funebrene	1473	3.09
Zingiberene	1490	46.71
Valencene	1492	7.61
Selina-4(14), 7(11)-diene	1495	1.03
Citronellyl n-butyrate	1501	19.34
α-Muurolene	1503	0.10
Cuparene	1505	0.38
α-Bisabolene	1507	0.05
β-Bisabolene	1513	0.15
γ-Cadinene	1515	0.06
β-Curcumene	1516	0.04

Components	Kovat's Index	% Area
δ-Cadinene	1518	0.10
Myristicin	1519	0.14
α-Cubebene	1522	0.43
β-Sesquiphellandrene	1525	0.06
trans-Calamenene	1529	0.04
cis-Cadina-1, 4–diene	1535	0.31
Selina-3,7-diene	1542	0.10
α-Agarofuran	1546	0.41
Sesquisabinene hydrate	1548	0.12
Epiglobulol	1551	0.76
2-Pentadecen-4-yne	1555	0.24
4-(2,6,6 -Trimethyl-2-cyclohexen-1-ylidene) -2- butanone	1557	0.11
(E)-Nerolidol	1558	0.06
Caryophyllene alcohol	1560	0.03
Globulol	1584	0.34
10-Epi-γ-Eudesmol	1597	0.33
Zingiberenol	1601	0.86
(-) Globulol	1604	0.19
1,5,5,8-Tetramethyl -3,7-Cycloundecadien -1-ol	1607	0.06
Agaruspirol	1631	0.03
γ-Eudesmol	1635	0.29
Muurolol	1641	0.02
β-Eudesmol	1649	0.05
α-Eudesmol	1652	0.15
Eudesm-4(14) - en-11-ol	1654	0.19
Ledene oxide	1668	0.03
8-Cedren-13-ol	1671	0.05
2,2,5,5-Tetramethyl tricyclo [6.3.0.0.(3,7)]-undec-1(8)-en-3-ol	1683	0.01
3,7,11-Trimethyl-2,10-docecadien-1-ol	1688	0.03
α-Bisabolol pentanoate	1695	0.02
(E)-Nuciferol	1705	0.01
Longifolene aldehyde	1715	0.50
Caryophyllic acid	1731	0.03
β-Bisabolene-12-ol	1739	0.02
1,8-Dimethyl-8,9-epoxy-4-isopropyl spiro (4.5)decan-7-one	1755	0.07
Heptadecanoic acid	1761	0.05
α-Atlantone	1773	0.00

In another study, *Z. officinale* essential oil from rhizome was analyzed from different locations in India. The following chemical components were identified: the highest concentration zingiberene (10.5% -16.6%), followed by e-citral (7.4% - 12.0%) and the rest was below 10%: z-citral (5.3% - 8.8%), β-farnesene (5.1% -8.4%), β-sesquiphellandrene (5.8% - 7.2%), camphene (4.9% - 7.6%), ar-curcumene (2.9% - 9.8%), and ocimene (0.9%- 6.5%). [70]

Table 13: Chemical composition of essential oil from *Z. officinale* rhizome [70]

Compound	Mizoram	Chennai	Sikkim Majhauley %	Sikkim Bhainsey %
Hexanal	0.2	0.4	0.3	0.2
2-Heptanone	0.1	0.1	0.1	0.1
α-Pinene	1.5	1.9	2.2	1.7
Camphene	6.1	6.6	7.6	4.9
Sabinene	1.0	0.5	1.4	1.3
β-Myrcene	1.0	1.3	1.7	1.7
p-Cymene	0.1	0.1	1.4	1.4
Ocimene	0.9	1.4	6.5	5.0
Limonene	1.3	6.4	1.9	2.9
β-Phellandrene	3.4	4.2	-	-
Linalool	1.7	0.6	1.3	0.7
Borneol	2.6	0.1	2.0	0.8
4-Terpineol	0.2	1.9	0.1	0.1
α-Terpineol	0.8	1.0	0.2	0.2
β-Citronellol	0.9	0.6	1.1	1.4
z-Citral	7.0	5.3	8.8	6.9
Geraniol	1.7	1.2	2.0	2.4
e-Citral	10.5	7.4	12.0	10.2
Geranyl acetate	0.6	0.1	0.4	0.6
β-Caryophyllene	0.1	2.2	0.1	0.1
α-Farnsene	0.3	0.2	0.3	0.3
ar-Curcumene	9.8	5.4	2.9	4.3
Zingiberene	10.5	15.2	16.6	16.6
β-Farnesene	5.1	5.6	6.0	8.4
β-Farnesol	5.8	4.9	3.9	4.5
Germacrene D	1.6	2.7	0.8	2.2
β-Sesquiphellandrene	7.1	7.2	5.8	6.8
Nerolidol	2.1	1.2	0.8	0.5
Cedrol	1.3	0.9	0.6	0.6
Total	84.3	86.6	88.8	86.8
Essential oil content (v/w)	0.3%	0.3%	0.32%	0.2%

When comparing these two studies, one can clearly see the differences in concentration and chemical composition of essential oils between different regions in India. Which brought the

authors to the conclusion that the chemical composition of the essential oil depends on the growing area and agroclimatic conditions. To name just few differences, *Z. officinale* essential oil concentration was much higher in Ghaziabad region with 46.71% while in other regions (Mizoram, Chennai, and Sikkim) the concentration was between 7.4% - 12.0%, β-phellandrene concentration in Ghaziabad region was 3.70% while in Mizoram concentration was 3.4%, in Chennai the concentration was 4.2% while in Sikkim the β-phellandrene was not detected. [69][70]

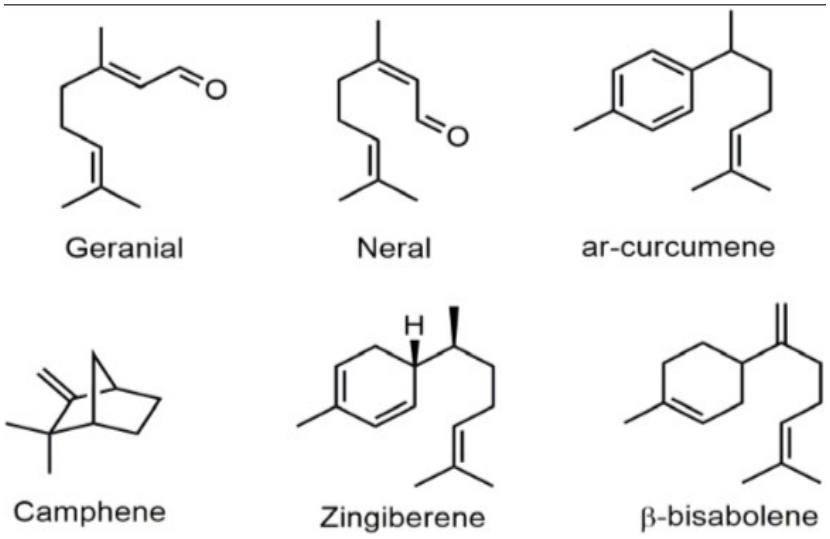

Figure 13: Chemical structures of some chemical components in *Z. officinale* essential oil from rhizome [71]

4.6.3 Use and scientific investigations

Numerous studies have proven the versatility of the use of *Z. officinale* essential oil, including antiemetic effect, phyto-estrogenic activity, anti-inflammatory effect, antimicrobial activity, antifungal activity, a good virucidal agent, prevention of coronary heart disease, prevention of gastric ulcers. Ginger has been shown to be beneficial against rheumatism and tumor growth. [70][71][72][73]

Following study has tested the essential oil from *Z. officinale* on the antimicrobial and antioxidant activity. Using agar and diffusion technique, the extracts were treated with five different organisms (*E. coli, S. aureus, Salmonella typhimurium, A.s niger* and *Bacillus subtilis*). The results showed that the three oils were effective against *B. subtilis* and *A. niger*, but that they were ineffective against *E. coli, S. aureus* and *S. typhimurium.* [74]
In another study, *Z. officinale* essential oil was shown to have a sedative effect and an anticholinergic effect on the central nervous system, while it showed no anxiolytic effect in the elevated-plus-size maze test. [75]

4.7 Kaempferia galanga L.

4.7.1 General

Kaempferia galanga L. belongs to the *Zingiberaceae* family. There are various synonyms for this species such as aromatic ginger, resurrection lily, lesser galangal, sand ginger; and in Hindi: Chandramula, Sidhoul, Marathi, Kapurkachri, Tamil, Kacholu. The rhizome is dark red to brown with an almost white interior. Usually, it has two till five leaves, dark green, elliptical to flat in shape and 8-15 cm long. The flower head is sessile and rises among the leaves. There are 4-12 flowers with white petals, the tube 2.5-5 cm long and the lobes 1.5-3 cm long. Lateral lobes are each approximately 2-2.5 cm x 1.5-2 cm. [76]
The plant grows to a maximum height of 30 cm, but is usually shorter and has cylindrical, fragrant root nodules. The flowering period begins in June and ends in September. The plant develops and grows mainly in the rainy season. The rhizomes are quite hard and heavy. [77]

Figure 14: *Kaempferia galanga* [78]

4.7.2 Chemistry of essential oils

This rhizome of *K.galanga* gives the oil a distinct yellow color and a characteristic odor. A total of 28 components of the essential oil of this rhizome has been identified. The main components of the oil are ethyl-methoxycinnamate (38.60%), ethyl-cinnamate (23.22%), 1,8-cineole (11.46%), trans-cinnamaldehyde (5.33%) and borneol (5.18%), followed by δ-3-carene (3.32%) and eucarvone (3.28%). It has a higher concentration of phenylpropanoids (67.62%) than monoterpenoids (29.57%) and sesquiterpenoids (2.01%). [79]

4.7.3 Use and scientific investigations

The two main components of the essential oil *K. galanga* (ethyl-p-methoxy cinnamate and ethyl-cinnamate) are responsible for the pharmacological effects of this plant. [80][81] Different chemical ingredients have different biological activity which is shown in Table 14.

Table 13: Chemical composition of essential oil from *K. galanga* rhizome [79]

No.	Compounds	RI[a]	Composition (%)
1	Tricyclene	926	0.03
2	α-Pinene	931	0.18
3	Camphene	957	0.31
4	δ-3-Carene	1,008	3.32
5	β-Cymene	1,020	0.21
6	1,8-Cineole	1,032	11.46
7	Chrysanthenone	1,125	1.95
8	*trans*-Pinocarveol	1,138	0.42
9	Camphor	1,146	1.60
10	Borneol	1,167	5.18
11	*p*-Cymen-8-ol	1,182	0.53
12	Eucarvone	1,250	3.28
13	*p*-Anisaldehyde	1,255	1.00
14	*trans*-Cinnamaldehyde	1,266	5.53
15	Bornyl acetate	1,287	0.26
16	Sabinyl acetate	1,291	0.84
17	α-Copaene	1,374	0.62
18	Cyperene	1,401	0.21
19	γ-Elemene	1,433	0.18
20	*trans*-Ethyl cinnamate	1,462	0.27
21	Ethyl cinnamate	1,470	23.22
22	γ-Muurolene	1,481	0.04
23	δ-Cadinene	1,523	0.28
24	Calamenene	1,520	0.13
25	Spathulenol	1,578	0.10
26	Caryophyllene oxide	1,586	0.14
27	Zierone	1,754	0.31
28	Ethyl *p*-methoxycinnamate	1,760	38.60
	Total identified		97.52
	Monoterpenoids		29.57
	Sesquiterpenoids		2.01
	Phenylpropanoids		67.62
	Others		1.00

Ethyl-p-methoxycinamate has different antibacterial activities, such as a significant biological activity against *Mycobacterium tuberculosis and Candida albicans*. [82][83] Anti-inflammatory and anti-inflammatory action results from the alcohol component of this plant namely, *K. galanga* alcohol extract was tested on animals in doses of 600 mg / kg and 1200 mg / kg of plant extract showing enviable anti-inflammatory effect and analgesic effect. [84]

In doses of 30, 100 and 300 mg/kg given subcutaneously, the aqueous extracts of Kaempferia galanga leaves show significant antiinflammatory effect in rats in a dose dependent manner. The main component of *K. galanga* responsible for anti-inflammatory action is ethyl-p-methoxycinnamate .[85]

In traditional medicine, rhizomes and the leaves of *K. galanga* are used to treat headache, swelling, stomachache, toothache, and rheumatism. [78][86]

Table 14: Some of the important chemical compounds present in *K. galanga* essential oil along with its biological activity [77]

S. No.	Chemical constituent	Area %	Biological activity
1.	Ethyl trans-p-methoxycinnamate	51.6 (9), 39.09 (Kasthuri) and 35.09 (Rajani) (11), 25.96 (13), 38.6 (14),18.42 (15), 14.3 (18)	• Anti-microbial (20–23) • Anti-cancer, Larvicidal and Anti-tuberculosis activity (15) • Anti-TB lead (24,25) • Nematicidal activity (17,19,26) • Mosquito repellent activity (27,28) • Angiogenesis inhibitor (31,32) • Anti-carcinogenic (34) • Anti-inflammatory (35)
2.	Ethyl cinnamate	16.5 (9), 18.83 (Kasthuri) and 13.14 (Rajani) (11), 6.31 (12), 23.2 (14), 29.48 (15), 31.12 (18)	• Larvicidal, Anti-carcinogenic and Nematicidal activity (15,17,19,26) • Larvicidal activity and mosquito repellent activity (27,28)
3.	Pentadecane	9.0 (9), 26.08 (13), 4.8 (18)	• Larvicidal activity and mosquito repellent activity (27,28)
4.	1,8-cineole	5.7 (9), 8.07 (Kasthuri) and 13.57 (Rajani) (11), 11.5 (14), 6.54 (15), 10.57 (18)	• Analgesic, Anti-inflammatory, Anti-nociceptive, Antibacterial, Cytotoxic, Anti-exudant, Anti-tumour, Vasorelaxant and fumigant activity (15)
5.	γ-car-3-ene	3.3 (9), 2.47 (13), 5.12 (18)	• Larvicidal activity and mosquito-repellent activity (27,28)
6.	Borneol	2.7 (9), 5.2 (14), 5.21 (15)	• Analgesic, Anti-coagulant and Anti-thrombotic activity (15)
7.	Carvone	11.13 (10)	–
8.	Eucalyptol	9.59 (10), 2.12 (13)	–
9.	Linoleoyl chloride	21.42 (12), 1.35 (15)	–
10.	Caryophyllene oxide	11.75 (leaf) and 4.37 (rhizome) (12)	–
11.	Cubenol	9.66 (12)	–
12.	Caryophyllene	5.60 (12)	–
13.	4-cyclooctene -1-methanol	4.61 (12)	–
14.	Limonene	3.22 (12)	–
15.	2-propeonic acid	63.36(12), 35.54 (13)	• Larvicidal activity and mosquito-repellent activity (27,28)
16.	Transcinnamaldehyde	5.3 (14)	• Nematicidal activity (26)
17.	γ-cadinene	9.81 (15)	• Anti-microbial, Anti-nociceptive activity and Antiviral activity (15)
18.	δ-carene	6.19 (15)	–
19.	Camphene	1.58 (15)	–
20.	α-pinene	1.32 (15)	• Anti-microbial, Anti-nociceptive activity and Antiviral activity (15)

In addition to the usual antimicrobial and anti-inflammatory effects, previous studies and experiments have demonstrated the antidiarrheal, vermicidal, and sedative effects of *K. galanga* rhizomes. [87]

Previous research has focused on the biological activity of the main components of essential oil, while by-products such as α-pinene are still insufficiently studied and there are not many studies on the biological activity of the by-product. In the future, more attention should be paid to the study of these components. *K. galanga* essential oil is also used in pharmaceutical industries, cosmetics, fragrances, food flavorings, and as well as in aromatherapy as an inhalation product and for massages to relieve anxiety,depression and stress. [77]

4.8 Cyperus rotundus L.

4.8.1 General

Cypers rotundus L. is a real example of a multi-purpose medicinal plant that has been used since ancient times and its medicinal properties have been confirmed by modern science. It belongs to the family of *Cyperaceae*, and it is the most numerous family in monocotyledons containing about 109 genera and approximately 5500 species. [88]

C. rotundus originates from India, but can also be found in other tropical, subtropical and temperate areas. Another name is walnut grass. It is a widespread, perennial plant. Rhizomes are nodular and grow individually from 1-3 cm long tubers. On the outside the tubers are black while the inside is reddish white and has a characteristic odor. The maximum height of the plant is 25 cm, it has linear leaves of dark green color, while the flowers are small with 2-4 petals composed of reddish-brown scales. The nut is triangular, oblong, yellow and black when mature. [89]

Figure 15: *Cyperus rotundus* [90]

4.8.2 Chemistry of essential oils

C. rotundus rhizome essential oil was identified and analysed by GC-MS. The following results were obtained: 35 main components were detected which makes up the 95.14% of the total of essential oil. α-cyperone was the main component with the highest concetration of 29.38%, followed by cyperene with 13.97%, all other components were below 10%. (Table 15) [91]

Table 15: Chemical composition of essential oil from *C. rotundus* rhizome [91]

No.	Compounds	RI*	Percentage (%)
1	α-Pinene	931	0.82
2	β-Thujene	967	1.95
3	β-Pinene	981	0.67
4	ρ-Cymene	1024	0.86
5	(d)-Limonene	1028	3.31
6	1,8-Cineole	1032	0.67
7	Linalool	1094	0.89
8	*trans*-Pinocarveol	1136	2.15
9	4-Terpinenol	1179	0.25
10	p-Cymen-8-ol	1184	1.67
11	α-Terpineol	1191	0.40
12	Myrtenol	1196	2.34
13	(S)-Verbenone	1211	0.74
14	*trans*-Carveol	1217	1.23
15	Carvone	1238	0.94
16	Bornyl acetate	1287	0.35
17	*Trans*-anethole	1290	1.65
18	α-Copaene	1374	1.44
19	β-Elemene	1388	0.67
20	Cyperene	1401	13.97
21	β-Gurjunene	1434	1.94
22	Aromadendrene	1441	0.14
23	γ-Muurolene	1473	2.29
24	β-Selinene	1483	6.47
25	α-Muurolene	1499	0.34
26	γ-Cadinene	1513	0.71
27	α-Cadinene	1536	0.11
28	α-Calacorene	1542	1.12
29	Spathulenol	1578	4.17
30	Caryophyllene oxide	1584	6.71
31	Viridiflorol	1588	0.30
32	Isolongifolen-5-one	1686	1.24
33	α-Cyperone	1746	29.38
34	Aristolone	1776	2.01
35	Nootkanone	1812	1.24
	Total		95.14
	Monoterpenoids		19.24
	Sesquiterpenoids		74.25
	Other		1.65

C. rotundus is characterized by four chemotypes in the composition of its essential oil, and thus four chemotypes were studied namely H-, K-, M- O-types. The research was conducted in different parts of the world, and thus the classification of different biological components in different types characteristic of the area was determined. According to the research and studies (Table 16) [92][93]:

- H-type from Japan contained α-cyperone(36.6 %), β-selinene (18.5 %), cyperol (7.4 %) and caryophyllene (6.2 %).
- M-type from Japan, Hong Kong,China,Vietnam and Taiwan showedd α-cyperone (30.7%), cyperotundone (19.4%), β-selin (17.8 %), cyperene (7.2 %) and cyperol (5.6 %).
- O-type from Thailand,Japan Hawaii, Philippines and Taiwan showed cyperene (30.8 %), cyperotundone (13.1 %) and β-elemene (5.2 %).
- K-type from Hawaii, showed cyperene (28.7%), cyperotundone (8.8%), patchoulenyl acetate (8.0%) and sugeonyl acetate (8.0%). [92]

Table 16: Comparison of major compounds of *C. rotundus* rhizomes oils from different countries [93]

	Oil percentage composition									
Constituents	1	2	3	4	5	6	7	8	9	10
α-pinene	-	-	-	-	-	-	-	-	-	(3.0-10.8)
β-pinene	-	-	-	-	-	-	-	-	-	(5.3-11.3)
α-copaene	-	-	-	-	-	-	(11.4-12.1)	-	-	-
cyperene	-	30.8	7.2	28.7	20.7	-	(8.4-11.1)	19.2	(20.4-30.9)	(1.6-2.6)
β-selinene	18.3	-	17.8	-	-	-	-	-	-	(4.6-5.1)
cyperotundone	-	13.1	19.4	8.8	25.0	12.1	--	-	8.8	-
α-cyperone	38.6	-	30.7	-	-	22.8	-	17.7	(4.5 – 25.2)	(7.9-11.0)
valerenal	-	-	-	-	-	-	(8.7-9.8)	-	-	-
caryophyllene oxide	-	-	-	-	-	-	(7.8-9.7)	-	-	(2.6-5.4)
petchoulenyl acetate	-	-	-	8.0	-	-	-	-	-	-
sugeonyl acetate	-	-	-	8.9	-	-	-	-	-	-

1= H-type; 2= O-type; 3= M-type; 4= K-type; 5= Hawaiian O-type; 6=Brazil; 7=India; 8=Nigeria; 9= Tunisia; 10= South Africa.

4.8.3 Use and scientific investigations

The largest number of studies and research have proven the wide spectrum of pharmacological action of *C. rotundus*.

The wide range of activities includes the following biological activities (Figure 16):

- Anti-inflamatory
- Antipyretic
- Analgesic and sedative
- Antiarthritic
- Anti-emetic
- Gastroprotetcive
- Antispastic
- Antidiarrhoeal
- Anticonvulsant
- Antihistaminic
- Anticancer
- Anti-obesity
- Antibacterial
- Antimalarial
- Antidiabetic [94]

All the pharmacological effects listed are related to one of the main constituents of the essential oil and are the result of these biological activities. [94]

Regarding the use for medical purposes, it has been proven that *C. rotundus* rhizome has a wide spectrum of action, and some of them are: analgesic,diuretic antispasmodic, aromatic, antitussive, carminative, emenagogic, litholytic, stimulant, sedative, vermifuga tonic and antibacterial,etc. It can be a good antidigestant. There are a lot of enzymes for carbohydrates and minerals that serve as catalysts for several biochemical reactions and helps with digestive problems. [95]

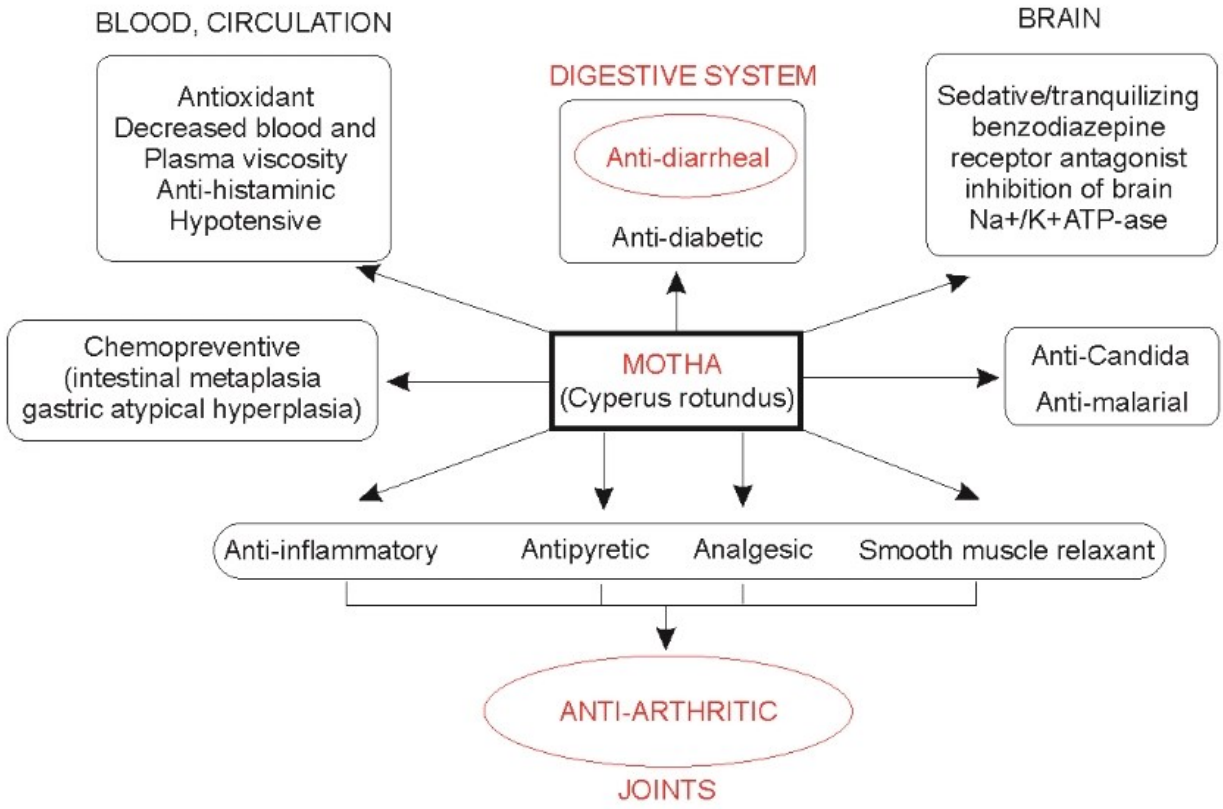

Figure 16: Pharmacological activities of *C. rotundus* [94]

C. rotundus essential oil is also widely used in the treatment of some everyday and common diseases and disorders. It has been also proven to have a positive effect in the treatment of menstrual problems and help with nausea, headaches, dyspepsia, bronchitis, coughs, diarrhea, bloating and other stomach problems. In addition to medical applications, the essential oil of *C. rotundus* is also used for cosmetic purposes, it is an aromatic component of perfumes, various lotions or preparations intended for facial skin. [95][96][97][98]

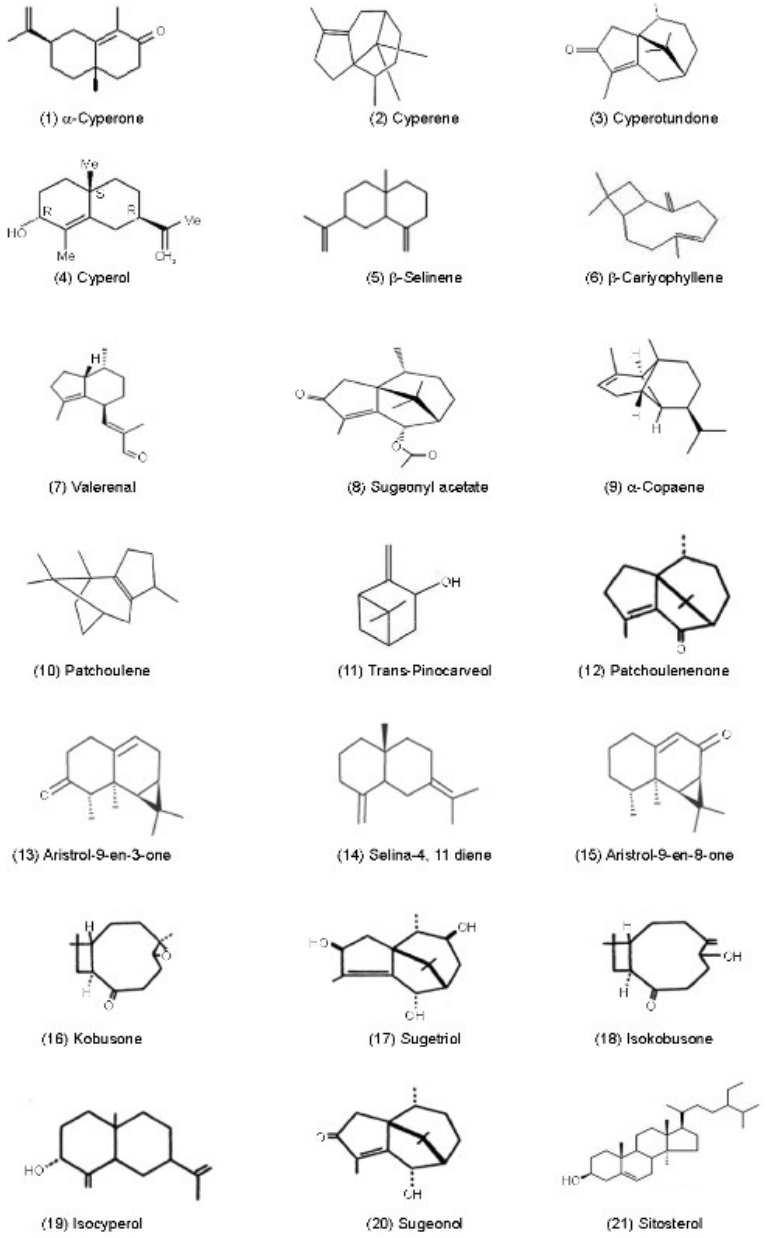

Figure 17: Chemical structures of some important compounds of *C. rotundus* [94]

Conclusio

For thousands of years, nature has been considered a valuable source of medicinal ingredients, and a numerous modern medicines have been derived from natural sources. Essential oils are well known for their antibacterial, antitumor, antidepressant, antiviral and antifungal properties, as well as for their scent, and are used for embalming, food preservation and as antimicrobial, analgesic, sedative, anti-inflammatory,local anesthetic and antispasmodic agents. The inhibitory effect of essential oils depends on the type of essential oil, the amount of oil used and the type of fungus and bacteria to which the oil is applied. Just to name a few examples from my thesis *Acorus calamus* the essential oil has an enormous inhibitory effect against the growth of fungi and as well as bacteria, for which it can be used to prevent the spoilage of food.

Apinia officinarum essential oil contains 1,8-cineole which has been proven that it lowers the proinflammatory cytokines such as TNF-α, IL-1β, and IL-6 in amyloid beta-treated cells and decreases the expression of NOS-2, COX-2 and NF-κB,thus enabling the treatment of neuroinflammation and is also effective protection against H1N1 influenza A virus. Essential oils from rhizome have not only been shown to be healthy and helpful for humans, they can also improve the well-being of animals. *Curcuma longa* essential oil can reduce skin photoaging in a UVB-irradiated nude mouse model and also has a high antibacterial activity.

The conclusion from this study is that essential oils and their constituents, as important plant products, are a promising source of new, alternative and natural medicines cause of their wide spectrum of different activities, they can be considered as an alternative to synthetic preservatives for food but their potential toxicity and safe dosage for use in food,cosmetic or pharmaceutical products should be considered. Also their use in modern medicine is increasing due to their pharmacological properties, and so is the interest of scientists who are conducting various studies to obtain more information about the use and applications of essential oils.

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References

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