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Chemical constituents and biological activities of essential oils of *Amomum* genus (Zingiberaceae)

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ABSTRACT

Amomum Roxb. includes the aromatic and medicinal plants native to tropical and subtropical Asia belonging to the family Zingiberaceae. Members of *Amomum* genus have been used for a long time in traditional medicine for the treatment of throat trouble, congestion of lungs, inflammation of eyelids, and digestive disorders, *etc*. *Amomum* essential oils have been studied for their chemical profiles in which limonene, allo-aromadendrene, 1,8-cineole, camphor, farnesyl acetate, α-pinene, β-pinene, caryophyllene, camphene, *D*-camphor, santolina triene, methyl chavicol, bornyl acetate, β-elemene, δ-3-carene, *etc*. were the major compounds. Furthermore, the oils extracted from *Amomum* plants have been reported to possess antimicrobial, antioxidant, insecticidal, larvicidal, cytotoxic, anti-scabies, and anti-inflammatory activities. This review focuses on the chemical constituents and biological activities of the essential oils isolated from the different plant parts of *Amomum* plants. The objective of the present review is to highlight therapeutic potentials and provide evidence for future medicinal applications of these species of genus *Amomum*.

KEYWORDS: *Amomum*; Zingiberaceae; Essential oil; Bioactivity

1. Introduction

Essential oils are complex mixtures of volatile compounds that are produced by aromatic plants as secondary metabolites. They are produced by many plant parts such as leaves, seeds, flowers, peels, berries, rhizome, root, bark, wood, resin, petals[1]. Essential oils are characterized by the presence of bioactive compounds belonging to different functional groups, including alkanes, alcohols, aldehydes, ketones, esters, and acids[2]. Many valuable natural products used in some fields such as pharmaceutics, perfumes, cosmetics, aromatherapy, phytotherapy, spices, nutrition, and insecticides have been shown by previous reports[3].

The Zingiberaceae family comprises approximately 50 genera and more than 1 500 species distributed throughout tropical Africa, Asia, and tropical America[4,5]. The Ginger plants are well-known for their medicinal values[6]. For instance, some plant parts of Zingiberaceae species such as rhizomes, leaves, fruits, and seeds were used to treat cough, sore throat, improve digestion, reduce pain, and heal bruises and scars[6,7]. Members of Zingiberaceae provided many useful products for medicines, spices, cosmetics, and essential oil as important natural resources[8,9]. Furthermore, the essential oils isolated from Zingiberaceae plants contain several medicinal compounds, including terpenes, alcohols, ketones, flavonoids, and phytoestrogens[9].

Amomum Roxb. is a genus belonging to Zingiberaceae family and there are approximately 188 species distributed widely in tropical and subtropical Asia, especially in northeast India and the Indochinese floristic region[5,10]. Members of *Amomum* are extensively used for traditional medicine or food in many countries. For instance, *Amomum subulatum* (*A. subulatum*), one of the popular *Amomum* species, has been used for throat trouble, congestion of lungs, inflammation of eyelids, digestive disorders, and in the treatment of pulmonary tuberculosis[11]. Seeds and fruits of *A. subulatum* are used in spices and can play a preventive role in the occurrence of gastrointestinal disorders and respiratory problems[12,13]. Additionally, the chemical composition and bioactivities of the essential oils isolated from several *Amomum* species have been reported in the previous studies[14–17].

In spite of several reports about chemical profiles and biological activities attributed to the essential oils of *Amomum* species, there is still scarce information about these aspects. The present review,

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therefore, elaborates comprehensive information on the chemical composition and biological activities of the essential oils isolated from many different plant parts of *Amomum* species.

2. Chemical profiles of *Amomum* essential oils

Analysis of chemical profiles of the essential oils isolated from *Amomum* species showed that the oils consisted of some chemical groups, including monoterpene hydrocarbons, oxygenated monoterpenes, sesquiterpene hydrocarbons, oxygenated sesquiterpenes, and non-terpenes. Different plant parts such as leaves, flowers, fruits, stems, seeds, pods, rhizomes, and roots were investigated in the previous studies[14–18]. The major compounds of the *Amomum* essential oils isolated from various plant parts are stated in Table 1.

Monoterpene hydrocarbons are the most abundant components found in the *Amomum* essential oils. β-Pinene was identified as the largest proportion of the essential oils isolated from six *Amomum* species, including *Amomum glabrum* (leaves)[14], *Amomum maximum* (leaves and stems)[15], *Amomum repoense* (leaves)[16], *Amomum uliginosum* (rhizomes)[17], *Amomum villosum* (*A. villosum*) (stems, roots, leaves, and rhizomes)[18–20], and *Amomum xanthioides* (*A. xanthioides*) (roots)[21,22]. α-Pinene was found as the most abundant component in the essential oils extracted from leaves, stems, roots, fruits, and flowers of *Amomum muricarpum* (*A. muricarpum*) in Vietnam[15]. Two other monoterpene hydrocarbons, limonene, and santolina triene were the major compounds of the leaf and rhizome oils of *Amomum aculeatum* and *Amomum newmanii* collected from Vietnam and India, respectively[23,24]. The oils of *Amomum longiligulare* (*A. longiligulare*) roots collected from Vietnam contained camphene as a major compound[25] whereas β-phellandrene was the most abundant constituent of the oils of the *Amomum rubidium* rhizomes[26]. Furthermore, other monoterpene hydrocarbons, including, α-neocallitropsene, β-myrcene, (*E*)-β-ocimene, δ-3-carene, and *p*-cymene were also reported in the oils of *Amomum agastyamalayanum* (rhizomes)[24], and *A. muricarpum* (leaves, stems, roots) as the major compounds[15].

Oxygenated monoterpenes, another group of chemical continents, were also found in *Amomum* essential oils. In the fruit oils of some *Amomum* species collected from Vietnam, China, and India such as *Amomum aromaticum* (*A. aromaticum*), *Amomum compactum*, *Amomum kravanh*, *A. subulatum*, and *Amomum tsao-ko* (*A. tsao-ko*), 1,8-cineole was found as the most abundant component[27–36] while this compound was also reported as the highest proportion in the oils of *Amomum rubidum* (*A. rubidum*) (leaves)[37], *A. subulatum* (pods, rinds, and seeds)[38–40], *A. tsao-ko* (pods and seeds)[38,41], *Amomum uliginosum* (rhizomes)[17] and *Amomum verum* (roots)[42]. Camphor was also found as the richest compound in the essential oils of *Amomum biflorum* (whole plants), *A. longiligulare* (fruits)[43], and *Amomum villosum* var. *xanthioides* whereas this compound in the oils of *A. villosum* fruits was the second highest percentage[44]. In the oils of the *A. villosum* fruits collected from China[45] and *A. xanthioides* fruits and seeds from Vietnam, bornyl acetate was the most abundant compound[22] while this compound was also present in the oils isolated from roots and fruits of *A. longiligulare* as one of the major component[25,43]. Terpinen-4-ol was the richest compound in the oils of *A. subulatum* leaves[46] while the other plant parts of this species contained the lower percentages[32,39,40]. Additionally, methyl chavicol, another compound belonging to oxygenated monoterpenes, had the highest percentage in the essential oils isolated from the rhizomes of *Amomum pavieanum*[47].

Another group of chemical continents which was found in *Amomum* oils was sesquiterpene hydrocarbons. β-Elemene presented in the essential oils extracted from leaves and stems of *A. xanthioides* collected from Vietnam as the richest component[22]. Caryophyllene was also found as the most abundant compound in the oils of the leaves and stems of *A. longiligulare* growing in Vietnam[25]. Allo-aromadendrene was the most abundant compound in the essential oils of *Amomum agastyamalayanum* rhizomes from south India[24]. Oxygenated sesquiterpenes were also reported in *Amomum* essential oils in which farnesyl acetate and spathulenol were identified as the highest percentage of chemical components in the essential oils of two species collected from Vietnam such as *Amomum gagnepainii* leaves[16] and *A. xanthioides* stems[21], respectively. The other oxygenated sesquiterpenes including α-bisabolol, zerumbone, humulene epoxide Ⅱ, and t-muurolol were also found as the major constituents in the oils of *Amomum biflorum* (whole plants)[48], *Amomum gagnepainii* (leaves)[16], *A. longiligulare* (leaves)[25], *A. muricarpum* (flowers)[15], respectively. On the other hand, decenal, the unique compound belonging to non-terpenes was found in the essential oils of the pods isolated from *A. tsao-ko*[38].

3. Biological activities of *Amomum* essential oils

3.1. Antimicrobial activity

Singtothong *et al*.[48] showed that the essential oils isolated from the whole plant of *Amomum biflorum* collected from Thailand could inhibit the growth of *Staphylococcus aureus* (*S. aureus*) with a minimum inhibitory concentration (MIC) value of 30 μg/mL. The essential oils of *Amomum kravanh* fruits from China showed significant activity against six bacterial pathogens, including three Gram-positive strains [*S. aureus*, *Staphylococcus albus*, *Bacillus subtilis* (*B. subtilis*)] and three Gram-negative bacteria [*Salmonella enterica*, *Shigella dysenteriae*, *Escherichia coli* (*E. coli*)] with MIC values of 5.0 mg/mL, 5.0 mg/mL, 2.5 mg/mL, 2.5 mg/mL, 1.25 mg/mL, and 2.5 mg/mL, respectively[29]. Recently, Nguyen *et al*.[14] demonstrated that the essential oils extracted from leaves and rhizomes of *Amomum glabrum* growing in Vietnam were able to resist against *S. aureus* with the MIC value of 5.67 μg/mL. Furthermore, the leaf oils of this species also had promising activity against *Enterococcus faecalis*, *Bacillus cereus*, and *Candida albicans* (*C. albicans*) with MIC values of 4.23 μg/mL, 67.98 μg/mL, and 1.56 μg/mL, respectively whereas MIC values of 18.67 μg/mL, 9.78 μg/mL and 10.23 μg/mL, respectively were shown by the rhizome oils towards the same microorganisms. Le *et al*.[52] demonstrated that the essential oils extracted from *A. rubidum* rhizomes collected from Bidoup Nui Ba National Park, Vietnam exhibited significant inhibitory activity on *Aspergillus niger* (*A. niger*) and *Fusarium*

Table 1. Major components identified from *Amomum* essential oils.

Species	Locality	Part	Major compounds	References
Amomum aculeatum	Hue, Vietnam	Leaves	Limonene (20.8%), valencene (18.0%), α-phellandrene (8.7%), α-pinene (6.9%), β-sequiphellandrene (6.1%)	[23]
Amomum agastyamalayanum	India	Rhizomes	Allo-aromadendrene (16.2%), β-pinene (8.7%), caryophyllene (8.5%), caryophyllene oxide (2.33), α-neocallitropsene (2.18%)	[24]
Amomum aromaticum	Vietnam	Fruits	1,8-Cineole (48.22%), geranial (9.24%), neral (6.72%), (*E*,*E*)-decenal (4.9%), α-terpineol (2.28%)	[14]
Amomum biflorum	Thailand	Whole plant	Camphor (17.6%), α-bisabolol (16.0%), camphene (8.2%), α-humulene (5.1%), spathulenol (3.3%)	[48]
Amomum compactum	China	Fruits	1,8-Cineole (47.6%), β-pinene (13.7%), α-terpineol (8.3%), limonene (7.8%), α-pinene (2.8%)	[28]
Amomum gagnepainii	Vietnam	Leaves	Farnesyl acetate (18.5%), zerumbone (16.4%), caryophyllene (10.5%)	[16]
Amomum glabrum	Nghe An, Vietnam	Leaves	β-Pinene (62.2%), α-pinene (13.1%)	[14]
		Rhizome	β-Pinene (53.7%), α-pinene (10.1%), fenchyl acetate (11.3%)	[14]
Amomum kravanh	Tianjin, China	Fruits	1,8-Cineole (43,0%), limonene (6.6%), β-pinene (5.4%), α-terpinyl acetate (11.2%), α-pinene (3.5%)	[28]
	Hainan, China	Fruits	1,8-Cineole (68.42%), α-pinene (5.71%), α-terpinene (2.63%), β-pinene (2.41%), α-terpinolene (2.25%)	[28]
Amomum longiligulare	Nghe An, Vietnam	Leaves	Caryophyllene (26.6%), α-pinene (15.6%), humulene epoxide Ⅱ (14.8%), α-humulene (12.5%)	[25]
		Stems	Caryophyllene (37.4%), α-humulene (16.5%), hexahydrofarnesyl acetone (10.0%), α-pinene (5.4%), eicosane (5.0%)	[25]
		Roots	Camphene (15.7%), hexadecanoic acid (10.0%), octadecanoic acid (8.6%), bornyl acetate (7.8%), endo-fenchyl acetate (4.8%)	[25]
	Ninh Thuan, Vietnam	Fruits	*D*-camphor (46.71%), bornyl acetate (31.81%), camphol (4.29%), *D*-limonene (3.80%), β-bisabolene (2.0%)	[43]
Amomum maximum	Vietnam	Leaves	β-Pinene (40.8%), β-elemene (10.9%), α-pinene (9.7%), β-caryophyllene (8.3%), β-cedrene (4.9%)	[43]
		Stems	β-Pinene (20.4%), β-elemene (12.8%), caryophyllene (10.3%), α-pinene (6.8%), β-phellandrene (4.2%)	[43]
		Roots	β-Pinene (28.0%), α-pinene (15.0%), β-phellandrene (11.6%), camphene (5.4%), β-elemene (2.5%)	[43]
Amomum muricarpum	Vietnam	Leaves	α-Pinene (48.4%), β-pinene (25.9%), limonene (7.4%), β-myrcene (2.8%), camphene (1.3%)	[43]
		Stems	α-Pinene (47.2%), β-pinene (9.2%), caryophyllene (4.3%), β-myrcene (4.1%), benzyl benzoate (3.8%)	[43]
		Roots	α-Pinene (54.7%), β-pinene (14.3%), β-phellandrene (8.3%), β-myrcene (3.2%), camphene (2.2%)	[43]
		Fruits	α-Pinene (29.3%), β-pinene (17.9%), zingiberene (6.3%), β-elemene (3.7%), β-sesquiphellandrene (3.5%)	[43]
		Flowers	α-Pinene (24.1%), β-pinene (14.1%), t-muurolol (13.0%), β-cubebene (4.1%), limonene (3.6%)	[43]
Amomum newmanii	India	Rhizomes	Santolina triene (42.2%), α-pinene (17.1%), β-pinene (3.2%), artemisia triene (3.1%), α-copaene (2.39%),	[24]
Amomum pavieanum	Chanthabu, Thailand	Rhizomes	Methyl chavicol (91.6%), β-pinene (1.7%), camphene (1.3%), α-pinene (1.0%)	[47]
Amomum repoense	Vietnam	Leaves	β-Pinene (33.5%), (*E*)-β-ocimene (9.6%), γ-terpinene (9.1%), α-pinene (8.4%)	[16]
Amomum rubidum	Lam Dong, Vietnam	Leaves	1,8-Cineole (37.7%), δ-3-carene (19.5%), limonene (16.3%), myrcene (2.7%), α-pinene (3.0%)	[37]
		Stem	δ-3-Carene (21.9%), limonene (17.8%), β-phellandrene (14.6%), α-pinene (5.8%), α-phellandrene (4.7%)	[37]
		Rhizomes	β-Phellandrene (16.1%), limonene (14.4%), δ-3-carene (13.9%), α-pinene (7.7%), β-pinene (6.9%)	[26]
Amomum subulatum	Delhi, India	Fruits	1,8-Cineole (77.4%), β-myrcene (5.0%), α-terpineol (4.9%), toluene (2.4%), terpinen-4-ol (2.3%)	[30]
	Delhi, India	Fruits	α-Terpineol (7.47%), terpinen-4-ol (5.01%) , *cis*-geraniol (4.05%), α-selinene (3.14%)	[32]
	Saudi Arabia	Fruits	α-Terpineol (7.04%), terpinen-4-ol (4.83%), *cis*-geraniol (3.54%), α-selinene (2.91%)	[32]
	Sikkim, India	Fruits	1,8-Cineole (56.89%), α-terpineol (8.08%), β-pinene (7.23%), *D*-nerolidol (6.63%), α-pinene (3.28%)	[33]
	New Delhi, India	Fruits	1,8-Cineole (65.39%), α-terpineol (10.15%), β-pinene (7.23%), α-pinene (4.06%), linalool oxide (3.23%)	[31]
	Haryana, India	Leaves	Terpinen-4-ol (29.87%), 1,8-cineole (18.69%), β-phallendrene (7.97%), γ-terpinene (6.67%), *p*-cymene (6.20%)	[46]

Table 1. Major components identified from *Amomum* essential oils (continued).

Species	Locality	Part	Major compounds	References
	India	Pods	1,8-Cineole (52.8%) α-terpineol (8.2%), limonene (6.9%), β-pinene (6.3%), α-pinene (4.3%)	[38]
	Himachal Pradesh, India	Seeds	1,8-Cineole (57.31%), α-terpineol(15.84%), limonene (11.76%), terpinen-4-ol (4.89%), nerolidol (3.79%)	[40]
	Nepal	Seeds	1,8-Cineole (60.8%), α-terpineol (9.8%), β-pinene (8.3%), α-pinene (6.4%), terpinen-4-ol (3.4%)	[39]
		Rinds	1,8-Cineole (39.0%), β-pinene(17.7%), α-terpineol (12.3%), α-pinene (4.8%), terpinen-4-ol (3.2%)	[39]
	Pakistan	Fruits	1,8-Cineole (72.27%), α-terpineol (13.3%), terpinen-4-ol (4.7%), limonene (2.9%), β-pinene (2.7%)	[34]
	Pakistan	Seeds	1,8-Cineole (55.37%), terpinyl acetate (11.66%), limonene (6.05%)	[49]
Amomum tsao-ko	China	Pods	1,8-Cineole (22.6%), geranial (7.8%), geraniol (7.0%), *trans*-2,3,3A,7A-tetrahydro-1*H*-indene-4-carbaldehyde (6.8%), (2*E*)-decenal (6.1%)	[38]
	China	Fruits	1,8-Cineole (23.87%), limonene (22.77%), 2-isopropyltoluene (6.66%), undecane (5.74%)	[36]
	China	Whole plant	1,8-Cineole (34.6%), α-phellandrene (5.8%), α-terpineol (4.0%), geraniol (4.8%), β-pinene (3.3%,)	[50]
	Guangxi, China	Fruits	1,8-Cineole (45.24%), geraniol (5.11%), geranial (4.52%), α-terpineol (3.59%), α-phellandrene (3.07%)	[35]
	Vietnam	Seeds	1,8-Cineole (30.6%), 2-decenal (17.3%), geranial (10.6%), neral (7.0%), α-terpineol(4.3%)	[41]
Amomum uliginosum	Malaysia	Rhizomes	β-Pinene (29.9%), α-pinene (10.4%), α-terpineol (7.6%), isopinocamphone (5.1%), 1,8-cineole (2.7%)	[17]
Amomum verum	Thailand	Shoots	1,8-Cineole (84.38%), limonene (6.15%), *p*-cymeme (4.87%), *trans*-*p*-mentha-2,8-dienol (1.27%), α-terpineol (1.07%)	[42]
Amomum villosum	China	Fruits	Bornyl acetate (49.16%), camphor (22.81%), *D*-limonene (7.51%), β-myrcene (2.93%)	[44]
	Yunnan, China	Fruits	Bornyl acetate (51.6%), camphor (19.8%), camphene (8.9%), limonene (6.2%), α-pinene (3.0%)	[45]
	Nghe An, Vietnam	Stems	β-Pinene (48.1%), α-pinene (16.9%), methyl chavicol (7.0%), limonene (3.9%), γ-terpinene (3.4%).	[18]
		Leaves	β-Pinene (53.6%), α-pinene (22.1%), limonene (4.2%), α-humulene (2.0%), γ-terpinene (1.2%)	[19]
		Roots	β-Pinene (41.6%), α-pinene (14.0%), δ-3-carene (4.8%), aromadendrene (2.0%), γ-terpinene (2.0%)	[19]
	Ha Tinh, Vietnam	Leaves	β-Pinene (56.6%), α-pinene(22.0%), limonene (3.8%), bicyclogermacrene (1.2%), γ-terpinene (3.5%)	[19]
		Roots	β-Pinene (34.7%), α-pinene (11.06%), limonene (4.4%), bicyclogermacrene (2.6%), α-terpinene (2.2%)	[19]
	Thanh Hoa, Vietnam	Leaves	β-Pinene (53.6%), α-pinene (24.5%), sabinene (13.6%)	[20]
		Stems	β-Pinene (38.8%), sabinene (19.2%), α-pinene (18.5%), β-caryophyllen (2.2%), γ-terpinen (1.8%)	[20]
		Rhizomes	β-Pinene (19.0%), sabinene (16.0%), α-pinene (9.1%), fenchyl acetate (7.0%), camphen (5.4%)	[20]
Amomum villosum* var. *xanthioides	China	Fruits	Camphor (36.07%), bornyl acetate (24.51%), *D*-limonene (9.23%), β-myrcene (4.98%)	[44]
Amomum xanthioides	Tuyen Quang, Vietnam	Leaves	β-Elemene (31.71%), δ-cadinene (10.69%), germacrene D (9.55%), bicycloelemene (8.12%), bicyclogermacrene (7.93%)	[22]
		Stems	β-Elemene (29.58%), spathulenol (26.89%), bicycloelemene(6.19%), germacrene D, (4.51%), bicyclogermacrene (4.19%)	[22]
		Roots	β-Pinene (29.59%), terpinen-4-ol (10.77%), α-terpinene (6.96%), α-pinene (5.56%), β-elemene (5.39%)	[22]
		Fruits	Bornyl acetate (37.21%), 2,6-dimethyl-2,4,6-octatriene (19.48%), camphene (14.62%), limonene (9.64%)	[22]
	Thua Thien Hue, Vietnam	Seeds	Bornyl acetate (27.26%), camphor (23.73%), *D*-limonene (12.26%), β-myrcene (10.89%), camphene (9.27%)	[51]
	Nghe An, Vietnam	Leaves	β-Elemene (20.3%), germacrene D (12.6%), bicyclogermacrene (9.4%), δ-cadinene (9.0%), bicycloelemene (7.8%), endo-1-bourbonanol (6.0%)	[21]
		Stems	Spathulenol (21.8%), β-elemene (20.4%), β-bisabolene (7.2%), germacrene D (6.5%), bicyclogermacrene (6.1%)	[21]
		Roots	β-Pinene(26.5%), terpinen-4-ol (14.5%), γ-terpinen (7.3%), α-terpinen (4.6%), α-pinene (4.1%)	[21]

oxysporum with MIC values of 50 g/mL. In another study, Le *et al.*[37] also reported that the leaf and stem oils of this species showed antibacterial activity against *Pseudomonas aeruginosa* (*P. aeruginosa*) with MIC values of 25 μg/mL and 50 μg/mL, respectively while MIC value of 50 μg/mL was shown by both oils towards *Fusarium oxysporum*. Also, the oils of *A. rubidum* stems were able to resist *C. albicans* (MIC value of 50 μg/mL)[37].

Alam *et al.*[32] reported that the essential oils isolated from the fruits of *A. subulatum* collected from Delhi, India and Al-Mehran, Saudi Arabia were able to resist *P. aeruginosa*, *E. coli*, and *Acinetobacter baumannii*. Similarly, the oils extracted from the fruits of three different cultivars of *A. subulatum* such as varlangy, seremna and sawney could inhibit the growth of bacterial and fungal pathogens, including *S. aureus* (MIC values of 5 mg/mL, 2.5 mg/mL, 2.5 mg/mL, respectively), *Klebsiella pneumonia* (MIC values of 5 mg/mL, 2.5 mg/mL, 5 mg/mL, respectively), *E. coli* (MIC values of 5 mg/mL only in seremna cultivar), *C. albicans* (MIC values of 2.5 mg/mL, 1.25 mg/mL, 1.25 mg/mL, respectively) and *A. niger* (MIC values of 5 mg/mL, 2.5 mg/mL, 5 mg/mL, respectively)[33]. Agnihotri *et al.*[53] reported that the fruit oils of *A. subulatum* collected from India exhibited significant inhibitory activity on 5 Gram-positive bacteria (*Bacillus pumilus*, *B. subtilis*, *S. aureus*, *Staphylococcus epidermidis*, and *Micrococcus luteus*), 2 Gram-negative bacteria (*E. coli* and *P. aeruginosa*), and 3 fungal strains (*C. albicans*, *A. niger*, and *Saccharomyces cerevisiae*).

Satyal *et al.*[39] demonstrated that the essential oils isolated from the seeds and rinds of *A. subulatum* showed significant activity against *Bacillus cereus* (MIC values of 625 μg/mL and 313 μg/mL), *S. aureus* (MIC values of 313 μg/mL and 625 μg/mL), *E. coli* (MIC values of 625 μg/mL and 1 250 μg/mL), *P. aeruginosa* (MIC values of 625 μg/mL and 1 250 μg/mL), *A. niger* (MIC values of 313 μg/mL and 19.5 μg/mL). In this study, Satyal *et al.*[39] also showed that the major components of the *A. subulatum* oils, including α-pinene, β-pinene, 1,8-cineole, and α-terpineol could inhibit the growth of 4 oral bacteria and one studied fungus. Rahman *et al.*[34] demonstrated that the fruit oils of *A. subulatum* growing in Pakistan showed good antifungal activity against 7 fungi, including *Aspergillus flavus*, *A. niger*, *C. albicans*, *Fusarium oxysporum* var. *lycopersici*, *Microsporum canis*, *Pseudallescheria boydii*, and *Trichophyton simii*. Meanwhile, the seed oils isolated from *A. subulatum* from Pakistan showed significant activity against 3 fungi (*Aspergillus flavus*, *C. albicans*, and *Candida utilus*) and 2 bacterial strains (*E. coli* and *Lactobacillus acidophilus*)[34]. Singh *et al.*[54] reported that the essential oils from *A. subulatum* leaves collected from India were found effective against two strains of *Aspergillus flavus*, Navjot 4NSt and Saktiman 3NSt, with 100% growth inhibition. Moreover, *A. subulatum* oils inhibited aflatoxin B1 production at 500 μg/mL[54].

Yang *et al.*[35] proved that the fruit essential oils of *A. tsao–ko* collected from China were resistant to 5 bacterial and fungal pathogens, including *B. subtilis*, *S. aureus*, *E. coli*, *Proteus vulgaris*, *Salmonella typhimurium*, *Candida* sp. and *Hansenula anomala* with MIC values of 3.13 g/L, 0.2 g/L, 1.56 g/L, 6.25 g/L, 6.25 g/L, 3.13 g/L, and 1.56 g/L, respectively. From another China sample, Cui *et al.*[50] showed the antibacterial activities of the whole plant oils of *A. tsao–ko* isolated by three efficient extraction methods including modified-solvent-free microwave extraction, solvent-free microwave extraction, and hydrodistillation. Consequently, the oils isolated through the modified-solvent free microwave extraction method showed the best antibacterial activity for 7 microorganisms, including *S. aureus*, *Staphylococcus epidermidis*, *B. subtilis*, *Propionibacterium acnes*, *E. coli*, *P. aeruginosa*, and *C. albicans* with MIC values of 5.86 mg/mL, 2.94 mg/mL, 5.86 mg/mL, 2.94 mg/mL, 5.86 mg/mL, 2.94 mg/mL, 5.86 mg/mL, respectively. On the other hand, the oil obtained *via* hydrodistillation and solvent-free microwave extraction methods could inhibit the growth of these microorganisms with MIC values of 5.94 mg/mL and 6.06 mg/mL, 2.98 mg/mL and 3.03 mg/mL, 5.94 mg/mL and 6.06 mg/mL, 11.89 mg/mL and 3.03 mg/mL, 5.94 mg/mL and 12.11 mg/mL, 6.06 mg/mL and 3.03 mg/mL, 24.25 mg/mL and 12.11 mg/mL, respectively. Recently, Tangjitjaroenkun *et al.*[42] reported that the oils from the *Amomum verum* shoots growing in Thailand were able to resist against three Gram-positive bacteria, six Gram-negative bacteria and one pathogenic fungus, including *B. subtilis* (MIC value of 2.5 mg/mL), *S. aureus* (MIC value of 1.25 mg/mL), *Staphylococcus saprophyticus* (MIC value of > 20 mg/mL), *E. coli* (MIC value of 1.25 mg/mL), *P. aeruginosa* (MIC value of > 20 mg/mL), *Salmonella typhimurium* (MIC value of 2.5 mg/mL), *Enterobacter cloacae* (MIC value of 0.625 mg/mL), *Klebsiella pneumonia* (MIC value of 2.5 mg/mL), *Proteus mirabilis* (MIC value of > 20 mg/mL), *C. albicans* (MIC value of 0.313 mg/mL).

3.2. Antioxidant capacity

Recent studies have shown the antioxidant activity of the essential oils isolated from several *Amomum* species[32,50,55]. For example, Alam *et al.*[32] demonstrated that the oils of *A. subulatum* fruits from India and Saudi Arabia were found effective against DPPH radical scavenger with the IC_{50} values of 219.38 mg/mL and 203.79 mg/mL, respectively. Additionally, Alam and Majumdar[55] showed that the fruit oils of three cultivars of *A. subulatum* collected from India, including seremna, varlangy and sawney were active on DPPH and ABTS radical cation. In the ABTS scavenging model, the IC_{50} values of the oils of the seremna, varlangy, and sawney were found to be 27.96, 31.34, and 32.49 μg/mL, respectively whereas these values in DPPH scavenging model were 172.3, 216.9, and 274.3 μg/mL, respectively. In another study, the antioxidant activity of the essential oils isolated from the whole plant of *A. tsao–ko* was also investigated using DPPH radical scavenging activity and β-carotene/linoleic acid bleaching assay. Accordingly, the IC_{50} value of the first assay was found to be 5.27 mg/mL while 0.63 mg/mL was the IC_{50} value of the later one[50].

3.3. Insecticidal, nematocidal and larvicidal activities

Wang *et al.*[36] reported that the essential oils and two major chemical components eucalyptol and limonene isolated from *A. tsao–ko* fruits showed insecticidal behaviour against the red flour beetle [*Tribolium castaneum* (*T. castaneum*)] and the cigarette beetle [*Lasioderma serricorne* (*L. serricorne*)]. Accordingly, limonene had the strong toxicity against *T. castaneum* and *L. serricorne* with LC_{50} values of 14.79 μg/adult and 13.66 μg/adult, respectively while another compound, eucalyptol, was able to resist against *T. castaneum* (LC_{50} value of 18.83 μg/adult) and *L. serricorne* (LC_{50} value of 15.58 μg/adult). Meanwhile, the essential oils of *A. tsao–ko* fruits possessed contact toxicity against *T. castaneum* and *L. serricorne* with LC_{50} values of 16.52 μg/adult and 6.14 μg/adult, respectively. Chen *et* *al*.[45] demonstrated that the essential oil of the *A. villosum* fruits and its major compounds, including camphor, camphene, limonene, and bornyl acetate had contact toxicity against *T. castaneum* and *L. serricorne*. This report showed that the toxicity against two beetles of the essential oils was found with LC_{50} values of 32.4 and 20.4 μg/adult, respectively. Furthermore, the toxicity against *T. castaneum* of four major compounds including limonene, camphene, camphor, and bornyl acetate was observed with LC_{50} values of 15.0, 21.6, 50.0, and 66.0 μg/adult, respectively. Meanwhile, these compounds exhibited stronger contact toxicity against *L. serricorne* than *T. castaneum* with LC_{50} values of 13.7, 19.9, 13.4, and 15.6 μg/adult, respectively[45].

Satyal *et al*.[39] showed that the essential oils of *A. subulatum* seeds were toxic to *Caenorhabditis elegans* (*C. elegans*), *Drosophila melanogaster* (*D. melanogaster*), and *Solenopsis invicta* × *richteri* (*S. invicta* × *richteri*) with LC_{50} values of 341, 441, and 1 500 μg/mL, respectively whereas the rind oils of this species also possessed the toxicity against *D. melanogaster* (LC_{50} value of 493 μg/mL) and *S. invicta* × *richteri* (LC_{50} value of 1 150 μg/mL). Additionally, four major chemical compounds of the essential oils from *A. subulatum*, including α-pinene, β-pinene, 1,8-cineole, and α-terpineol also had nematocidal and insecticidal activities. Among four components, α-pinene and β-pinene were only marginally toxic to *C. elegans* (LC_{50} value of >2 500 μg/mL) and *S. invicta* × *richteri* (LC_{50} value of >1 000 μg/mL) but strongly toxic to *D. melanogaster* (LC_{50} value of 161 μg/mL and 178 μg/mL, respectively). 1,8-Cineole was also highly toxic to *C. elegans* (LC_{50} value of 227 μg/mL), *D. melanogaster* (LC_{50} value of 234 μg/mL), and *S. invicta* × *richteri* (LC_{50} value of 294 μg/mL). Meanwhile, α-terpineol had the strong toxicity against *D. melanogaster* and *S. invicta* × *richteri* with the LC_{50} value of 188 μg/mL and 287 μg/mL, respectively, but this compound was weakly toxic to *C. elegans* with the LC_{50} value of 2 180 μg/mL[39]. Recently, Le *et al*.[26] showed that the essential oils isolated from the rhizomes of *A. rubidum* could display larvicidal activity against *Aedes aegypti* with the LC_{50} values of 22.85 and 22.62 μg/mL at 24 h and 48 h, respectively.

3.4. Cytotoxic activity

The cytotoxic activity of the essential oils and their major chemical compounds isolated from seeds and rinds of *A. subulatum* was assessed against the breast cancer (MCF-7) cell line using MTT assay[39]. The results showed that the seed and rind oils showed cytotoxic activity with 19.4% and 31.2% mortality on MCF-7 cell at 100 μg/mL, respectively. Meanwhile, four compounds, including α-pinene, β-pinene, 1,8-cineole and α-terpineol possessed the cytotoxic activity with 16.8%, 30.4%, 3.7% and 16.1% mortality on MCF-7 cell at 100 μg/mL, respectively[39]. By using MTT assay, Tangjitjaroenkun *et al*.[42] have recently demonstrated that the essential oils from *Amomum verum* shoots were able to kill human prostate adenocarcinoma cells (DU145) with the IC_{50} values of slightly more than 0.40 mg/mL, approximately 0.40 mg/mL and 0.185 mg/mL for 1, 4, and 7 d, respectively.

3.5. Anti-inflammatory activity

Nguyen *et al*.[27] showed the anti-inflammatory effects of the essential oils isolated from the fruits of *A. aromaticum* in RAW264.7 murine macrophage model. The oils strongly inhibited the production of nitric oxide in LPS-induced RAW264.7 cells (IC_{50} value of 0.45 μg/mL). Furthermore, this study also demonstrated the effects of the *A. aromaticum* oils on the two enzymes of inflammation process, inducible nitric oxide synthase, and cyclooxygenase-2. By using Western blot analysis, the inhibitory effects of *A. aromaticum* oils on both enzymes were still observed significantly although the concentration of the oils was low (0.3 μg/mL)[27]. Alam *et al*.[32] reported the anti-inflammatory activity of the essential oils of *A. subulatum* fruits collected from India and Saudi Arabia using a bovine soluble albumin denaturation method. As a result, the percent inhibition of protein denaturation by the oils of India and Saudi Arabia were 69.09% and 66.81% at 100 mg/mL, respectively. Moreover, the IC_{50} value for the Indian oils was 53.12 mg/mL while that of Saudi Arabian oils was 57.94 mg/mL[32].

Table 2. Biological activity of essential oil isolated from various plant parts of *Amomum* species.

Biological activity	Species	Part oils	References
Antimicrobial activity	*Amomum biflorum*	Whole plants	[48]
	Amomum glabrum	Leaves and rhizomes	[14]
	Amomum kravanh	Fruits	[29]
	Amomum rubidum	Rhizomes, leaves, and stem	[37,52]
	Amomum subulatum	Fruits, seeds, rinds, and leaves	[32-34,39,49,53,54]
	Amomum tsao-ko	Whole plant, fruits	[35,50]
	Amomum verum	Shoots	[42]
Antioxidant activity	*Amomum biflorum*	Whole plant	[48]
	Amomum subulatum	Fruits	[32,55]
	Amomum tsao-ko	Whole plant	[50]
	Amomum verum	Shoots	[42]
Insecticidal activity	*Amomum subulatum*	Seed and rind	[39]
	Amomum tsao-ko	Fruits	[36]
	Amomum villosum	Fruits	[45]
Larvicidal activity	*Amomum rubidum*	Rhizomes	[26]
Cytotoxic activity	*Amomum subulatum*	Fruits	[39]
	Amomum verum	Shoots	[42]
Anti-inflammatory	*Amomum aromaticum*	Fruits	[27]
	Amomum subulatum	Fruits	[32]
Anti-scabies activity	*Amomum subulatum*	Leaves	[46]

3.6. Anti–scabies activity

Sarcoptes scabiei is the main itch mite that causes ectoparasitic infestation in humans[56] with pruritic lesions and papules on the surface of the skin[57]. Sharma *et al*.[46] showed the anti-scabies potential of the essential oils extracted from *A. subulatum* leaves against this itch mite using contact bioassay method. As a result, at 1% concentration, the *A. subulatum* oils with anti-scabies potentials of 33.3%, 45.6%, 56.6% and 80% could eliminate *Sarcoptes scabiei* within 20, 40, 60 and 80 minutes, respectively while these percentages were 42.4%, 63.3%, 83.3% and 100% at 5% concentration oils. Additionally, the anti-scabies activity increased at 10% concentration oils with 100% mortality within 60 minutes.

Biological activities of essential oil isolated from various plant parts of *Amomum* species are summarized in Table 2.

4. Conclusion

In this article, the relevant kinds of literature were used to summarize the chemical profiles and biological activities of the *Amomum* essential oils. Based on different geographic regions where these *Amomum* plants were collected, the present article showed the diversity of quantitative and qualitative compounds of the oils. Additionally, the bioactivities of the essential oils and the major chemical compounds of the oils isolated from many plant parts of *Amomum* species have shown therapeutic potentials, which provides evidence for future medicinal applications of these species of genus *Amomum*.

Conflict of interest statement

The author declares that there is no conflict of interest.

Author's contributions

The present review was designed by HTV. HTV searched and handled the data, drafted the manuscript and resolved all the queries of editors and reviewers.

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