Review

A systematic review on essential oils and biological activities of the genus *Syzygium* (Myrtaceae)

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Syzygium belongs to the myrtle family, Myrtaceae with about 1800 species and located in the tropical region of Asia. The species have economic, medicinal, and pharmacological properties as well as being a source for pharmacochemistry studies. The local populations often use this species for different medicinal purposes, like to treat diabetes, dysentery, stomach-ache, cold, and ulcer. The objective of this study was to review the essential oils of the genus *Syzygium* and their biological activities. The data were collected from the scientific electronic databases including SciFinder, Scopus, Elsevier, PubMed, and Google Scholar. A total of twenty-six *Syzygium* species have been reported for their essential oils and biological activities. Sesquiterpenes were identified as the major group components for *Syzygium* species with the presence of α,β-caryophyllene, caryophyllene oxide, α-cadinol, germacrene D, viridiflorol, nerolidol, together with monoterpenes, α-pinene, β-pinene, o-cymene, β-ocimene, and limonene. The essential oils also presented remarkable bioactivities such as antioxidant, antibacterial, antifungal, antimalarial, acetylcholinesterase, anti leishmanicidal, cytotoxicity, larvicidal, oviposition deterrent, toxicity, genotoxicity, antimicrobial, α-amylase, anti-inflammatory, and molluscicidal properties. Hence, these studies may contribute to the rational and economic exploration of *Syzygium* species since it has been identified as potent natural and alternative sources to the production of new herbal medicines.
Keywords: Essential oil, *Syzygium*, caryophyllene, pinene, antioxidant, antimicrobial

1. INTRODUCTION

The Myrtaceae family includes around 55,000 species, classified into two subfamilies, 17 tribes, and 142 genera [1]. The name derives from the shrub '*Myrtus*' which is located near the Mediterranean in North Africa and South America. The plant contains both trees and shrubs and was an ecologically important angiosperm family [2]. They are generally found in an environment that is a waterlogged and humid rain forest. Most of them are bisexual with polysemous and actinomorphic, the flowers have inferior ovaries that are partially or fully developed, while the fruits are generally fresh or dry [1]. Many of these members of the family have paramount uses in history as a traditional medicine in divergent ethnobotanical practices throughout the tropical and subtropical world [2].

Syzygium is the largest genus in the Myrtaceae family located in a tropical region with high diversity in Asia [1]. About 1800 species of *Syzygium* were recorded and mainly found in Southern and Southeast Asia, Southern China, Australia, New Caledonia, and some in East Africa, Madagascar, Mascarenhas Islands, Southwest Pacific Islands, Taiwan, and Southern Japan [3]. *Syzygium* species present economic and medicinal consequentiality and pharmacological proprieties being a potential source for pharmacochemistry studies. Meanwhile, traditional communities utilise the infusions and decoction leaves of *Syzygium cumini* and *S. aqueum* to treat diabetes, stomach pains, and dysentery [3]. *Syzygium* species can be trees with thick, granular bark, twigs usually glabrous, the leaves are opposite, entire, penninerved, usually gland-dotted; lateral nerves united, forming a clear or faint intramarginal vein. The flowers are bisexual, in terminal or axillary corymbose cymes or panicles; calyx tube hemispherical, globose, or turbinate, tube produced above the summit of the ovary, lobes four or five, ovate to suborbicular, imbricate; petals four or five, orbicular, pellucid-glandular; stamens numerous, filaments inflexed in bud; staminal disc broad or absent; anthers globose; ovary inferior, two-celled; ovules few to several in each cell; style 1, subulate, stigma simple. The fruit is a berry, one-celled, with a few seeds [3]. *Syzygium* is one of the most common tree genera in the forest ecosystem, presenting nectariferous flowers, often in mass and typically fleshy fruits; it is used as food by birds, insects, and small and large mammals [3].

Essential oils, which serve as secondary metabolites, involve complex mixtures of natural compounds and versatile organic structures [4]. They are an involute cumulation of terpenic compounds, especially monoterpenes, sesquiterpenes, alcohols, aldehydes, ethers, esters, ketones, and phenols that are mainly responsible for aroma and odour. The oils are mainly responsible for the fragrance in spice and condiments, as well as used as a repellent agent in insecticides and herbicides [5]. Essential oils from aromatic and medicinal plants have been known to possess biological activity since antiquity, most notably antibacterial, antifungal and antioxidant properties [6]. Nowadays, researchers around the world produce medicines from the essential oils of natural products like plants.

Hence, the review regarding *Syzygium* essential oils must be done to simplify and compile the information. The information available on the *Syzygium* essential oils of various species was searched thoroughly via electronic search (SciFinder, Scopus, Elsevier, Pubmed, Google Scholar, and Web of Science) and the articles published in peer-reviewed journals were collected via a library search. However, *S. aromaticum* essential oils have been subject to several reviews, which will not be repeated here [7-9]. The review aims to compile the information regarding their medicinal uses, chemical composition, and bioactivities of the essential oils from the genus *Syzygium*.

2. SEARCH STRATEGY

The protocol to perform this study was developed following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement (PRISMA) [10] (a) the first step was to exclude duplicate articles, (b) titles and abstracts were then read and the inclusion and exclusion criteria were applied and (c) all articles resulting from this stage were read in full, and the inclusion and exclusion criteria were applied again. Figure 1 shows the flow diagram of the identification and selection of the articles. Following this step, we reached the articles chosen for this study. This systematic review was conducted through searches using Scopus, Medline, Scielo, ScienceDirect, SciFinder, and Google Scholar. The keywords used were '*Syzygium*', 'essential oil', and 'biological activity' articles over the period from the beginning of the database until May 2021. In addition, as a second search strategy, we included studies obtained by a manual search of the reference lists of the included studies. Articles on the genus of *Syzygium* that reported traditional uses, essential oils, and their biological activities were included (except for *Syzygium aromaticum*). The inclusion of articles considered the following criteria: (1) type of publication - original journal articles, (2) only articles in English, Portuguese, and Spanish, (3) articles must present the chemical composition of essential oils, (4) articles must discuss the biological activity of the essential oils. The following were used as the exclusion criteria: (1) articles that did not show the search terms in the title and in the abstract; (2) articles reported on essential oils of *Syzygium aromaticum* (3) review articles, (4) full-text articles not found, and (5) articles that did not show the composition of the essential oils.

3. MEDICINAL USES OF THE GENUS *SYZYGIUM*

Since antiquity, medicinal plants have been commonly used amongst rural inhabitants worldwide. Herbal medicines are widely used for the treatment of differ-

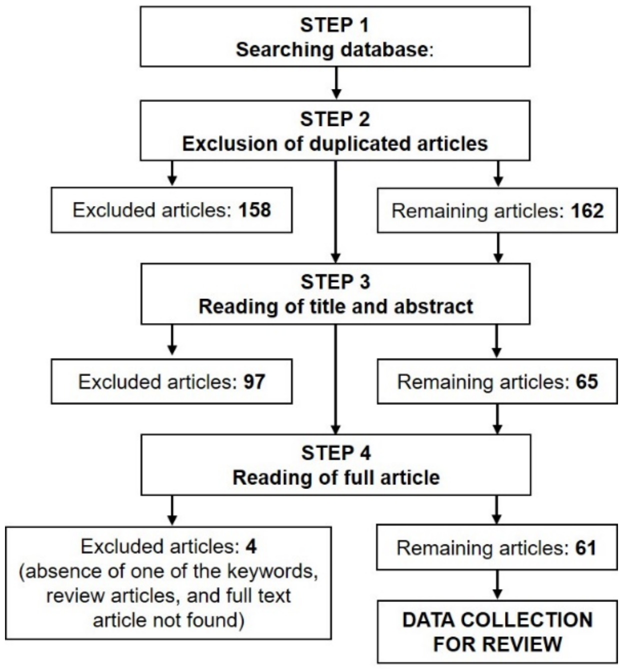

Figure 1 - PRISMA flow diagram of included studies

ent types of diseases such as skin and throat infections and other diseases in developing countries [11]. Natural products have been an integral part of the archaic traditional medicine systems such as Ayurveda, Chinese, and Egyptian [12]. People have been using various parts of the plant such as the leaf, stems, roots, flowers, and seeds extracted for the benefit of humans and used as traditional medicine [6]. *Syzygium* is known to be rich in volatile oils, mainly the part of the fruit used is edible and used for traditional medicines in divergent ethnobotanical practices [13]. Recently, *Syzygium* species have been used to treat diabetes, dysentery, stomach-ache, cold, and ulcer [11]. *Syzygium aromaticum* and *S. cumini* are, arguably, the most useful, with their fruits and leaves used as components of multiple traditional therapies [14]. In India, *Syzygium cumini* is one of the best-known species and it is very often cultivated locally where it is known as jambolan [13]. Table I shows several *Syzygium* species and their medicinal uses [11-23].

4. CHEMICAL COMPOSITIONS OF *SYZYGIUM* ESSENTIAL OILS

In earlier reports, there are twenty-six *Syzygium* species described on the essential oil composition [24-58]. Most of the species were identified in India where fifteen species were reported. Besides, six species were reported in Vietnam, and two species in Mauritius, Thailand, Germany, Pakistan, Nigeria, Egypt, and

Table I - Medicinal uses of several *Syzygium* species

Species	Part	Traditional uses
S. cumini	Leaf	Used to treat diabetes, opium poisoning, centipede bites, renal problems, dysentery, inflammation, leucorrhoea, stomachache, fever, dermopathy, constipation, inhibition of blood discharge in the faces, and reduce radiation-induced DNA damage, prescribed for nausea, vomiting, bleeding disorders, and metrorrhagia [11]
	Fruit	Helps to convert starch into energy which helps in regulating blood sugar levels and possesses a low glycemic index, gastric problems, anorexia, stomachic, astringent, antiscorbutic, diuretic, diabetic, reduced splenomegaly, prevents chronic diarrhea, excellent food remedy for hemorrhoids and liver disorders, abdominal diseases such as loss of appetite, abdominal pain, dysentery, and irritable bowel syndrome [15]
	Bark	To treat dysentery, repeated abortion, and headache [16]
	Seed	To treat sores and ulcers, cold, cough, fever, skin diseases like rashes, the genitourinary tract ulcers, stoppage of urinary discharge, mouth, throat, and intestine infections [16]
S. aqueum	Leaf	Used for stomach pains and dysentery [3]
S. cordatum	Bark	To treat amenorrhea, anemia, burn, chest complaints, emetics, gonorrhea, respiratory ailments, sexually transmitted infections (STIs), sores, and tuberculosis [17]
	Leaf	Used to treat colds, fever, gastro-intestinal complications, herpes simplex, herpes zoster, pre-hepatic jaundice, skin rash, and stomach problems [17]
	Root	Used as treat cough, diarrhea, dysentery, malaria, malaria, wounds, and headache [17]
	Fruit	To treat wound in the mouth [17]
S. polyanthum	Leaf	Used for antiulcer, antidiabetes, anti-inflammatory, and antidiarrhea treatment [18]
S. caryophyllatum	Fruit	Treating diabetes [19]
S. aromaticum	Clove	Used to relieve the stomach pain, the pain of muscle cramps and some nerve conditions, nausea, vomiting, diarrhea, hernia, bad breath, toothache, skin counterirritant, and mouth and throat inflammation [20]
S. samarangense	NM	For the treatment of fever and diarrhea [21]
S. malaccense	Bark	Used for stringent, treat cracked tongue, itching and diuretic, blood pressure, respiration, alleviate edema dysentery, antibiotic, mouth ulcer and used by women with irregular menstruation [22]
S. curanii	Leaf	Cure for high blood sugar [22]
S. jambos	Flower	Tonic for the brain and liver, diuretic, reduce fever, diarrhea, dysentery, diabetics, anesthetic property and catarrh. The leaf decoction is applied to eyes sore, emetic and cathartic, relieve asthma, bronchitis and hoarseness [22]
S. lineare	Leaf	Astringent, refrigerant, diuretic, to cool the body, and increase stamina [22]
S. polycephalum	Fruit	Used for curing high blood sugar [22]
S. suboriculare	NM	Used to treat coughs and colds, diarrhea, and dysentery [23]
S. moorei	NM	Antiseptic properties [23]
S. francisii	NM	Antiseptic properties [23]
S. grande	NM	Antiseptic properties [23]
S. forte	NM	Antiseptic properties [23]
S. guineense	NM	Antihypertensive properties [23]

Table II - Major components identified from several *Syzygium* essential oils

Species	Locality	Part	Extraction	Method	Total components %	Major groups %	Major components %
S. samarangense	Mauritius	Leaf	Hydro-distillation	GC-MS (HP-ınnowax FSC)	-	-	β-Pinene (21.3%), α-pinene (8.9%), γ-terpinene (7.9%), limonene (7.7%), *p*-cymene (5.9%) [25]
	Thailand	Leaf	Hydro-distillation	GC-MS (BPX-5)	11 (77.03%)	-	*o*-Cymene (54.33%), α-pinene (7.14%) [26]
	Germany	Leaf	Hydro-distillation	GC-MS (ZB-5)	91 (86.30%)	Sesquiterpene hydrocarbons (47.44%)	Germacrene D (21.62%), cuminyl aldehyde (10.56%), β-caryophyllene (5.93%), β-cadinene (5.25%) [27]
	India	Leaf	Hydro-distillation	GC-MS (CP-Sil-5 CB)	25 (99.24%)	Monoterpene hydrocarbons (30.27%)	Viridiflorol (15.05%), β-pinene (11.64%), 1-naphthalenol (11.07%) α-pinene (9.61%), α-cubebene (7.71%) [28]
	Nigeria	Leaf	Hydro-distillation	GC-MS (CP-Sil-5 CB)	40 (90.3%)	-	α-Cadinol (12.7%), juniper camphor (12.5%), caryophyllene oxide (8.2%), δ-cadinene (5.7%) [29]
S. coriaceum	Mauritus	Leaf	Hydro-distillation	GC-MS (HP-ınnowax FSC)	-	-	(*E*)-β-Ocimene (24.4%), (*Z*)-β-ocimene (10.7%), α-guaiene (12.6%), β-selinene (9.7%), myrcene (7.8%), δ-guaiene (7.2%) [25]
S. cumini	Pakistan	Leaf	Hydro-distillation	GC-MS (HP-5)	73 (93.82%)	Monoterpene hydrocarbons (27.00%)	Fenchol (4.22%), 5-methyl-1,3,6-heptatriene (4.90%), *cis*-β-ocimene (4.40%), γ-cadinene (4.09%) [11]
	India	Leaf	Hydro-distillation	GC-MS (HP-5)	25 (95.66%)	Oxygenated sesquiterpenes (51.43%)	τ-Cadinol (21.44%), τ-muurolol (12.01%), globulol (7.98%), caryophyllene (6.69%), δ-cadinene (6.56 %), α-pinene (6.32 %) [15]
		Leaf	Hydro-distillation	GC-MS (Elite-5)	- (93.6%)	Monoterpene hydrocarbons (62.5%)	α-Pinene (17.2%), (*Z*)-β-ocimene (10.9%), (*E*)-β-ocimene (9.6%), β-pinene (8.6%), δ-cadinene (7.5%), β-myrcene (5.4%) [30]
		Leaf	Hydro-distillation	GC-MS (Elite-5)	66 (95.3%)	Monoterpene hydrocarbons (38.8%)	α-Pinene (21.5%), α-terpinene (9.5%), δ-cadinene (8.3%), *trans*-□-ocimene (6.8%) [31]
		Fruit	Hydro-distillation	GC-MS (Elite-5)	34 (99.3%)	Monoterpenes hydrocarbons (41.9%)	α-Cadinol (25.8%), α-pinene (12.4%), β-pinene (8.0%), myrcene (8.4%), δ-cadinene (7.7%), α-terpinene (7.4%) [31]
		Fruit	Hydro-distillation	GC-MS (HP-5)	32 (90.35%)	-	α-Gurjunene (38.35%), α-caryophyllene (7.15%), guaiol (7.00%), β-caryophyllene (6.96%), aromadendrene (6.62%), α-selinene (5.20%) [32]

Continua Tabella II

Species	Locality	Part	Extraction	Method	Total components %	Major groups %	Major components %
	Thailand	Leaf	Hydro-distillation	GC-MS (BPX-5)	15 (87.50%)	-	Terpinolene (19.08%), γ-terpinene (16.63%), (*E*)-caryophyllene (12.25%), platyphyllos (9.69%), *o*-cymene (7.34%), α-humulene (5.58%) [26]
	Brazil	Leaf	Hydro-distillation	GC-MS (HP-5)	38 (99..0%)	Monoterpene hydrocarbons (34.48%)	α-Pinene (21.20%), globulol (15.30%), eugenol (11.20%), α-terpineol (8.88%), aromadendrene (6.79%), limonene (6.08%) [33]
		Leaf	Hydro-distillation	GC-MS (HP-5)	38 (95.50%)	Monoterpene hydrocarbons (57.00%)	α-Pinene (22.20%), limonene (7.30%), *cis*-β-ocimene (10.20%), *trans*-β-ocimene (5.88%), α-terpineol (7.00%), β-caryophyllene (9.45%), α-humulene (5.50%) [34]
		Leaf	Hydro-distillation	GC-MS (DB-5)	11 (99.98%)	Monoterpene hydrocarbons (87.12%)	α-Pinene (31.85%), (*Z*)-β-ocimene (28.98%), (*E*)-β-ocimene (11.71%), (*E*)-β-caryophyllene (5.02%), β-pinene (5.57%) [35]
		Leaf	Hydro-distillation	GC-MS (Restex RTX-5)	12 (75.68%)	-	α-Caryophyllene (25.24%), β-caryophyllene (16.00%), α-terpineol (9.08%), *epi*-globulol (5.23%) [16]
	Egypt	Leaf	Hydro-distillation	GC-MS (HP-5)	-	-	α-Pinene (17.26%), α-terpineol (13.88%), β-pinene (11.28%), *cis*-ocimene (11.27%), *trans*-caryophyllene (6.96%) [36]
		Leaf	Hydro-distillation	GC-MS (HP-5)	-	-	α-Pinene (17.26%), α-terpineol (13.88%), β-pinene (11.28%) [37]
		Leaf	Hydro-distillation	GC-MS (HP-5)	49 (98.30%)	-	α-Pinene (32.32%), β-pinene (12.44%), *trans*-caryophyllene (11.19%), 1,3,6-octatriene (8.41%) [38]
S. nervosum	Vietnam	Leaf	Hydro-distillation	GC-MS (ZB-5)	61 (90.2%)	Monoterpene hydrocarbons (31.7%)	(*Z*)-β-Ocimene (20.3%), caryophyllene oxide (13.2%), (*E*)-caryophyllene (12.1%), α-pinene (5.2%) [39]
S. hancei	Vietnam	Leaf	Hydro-distillation	GC-MS (HP-5)	50 (97.30%)	Sesquiterpene hydrocarbons (80.87%)	γ-Guaiene (11.07%), β-caryophyllene (9.11%), *cis*-calamenene (7.46%), α-copaene (6.97%), *trans*-cadina-1,4-diene (5.09%) [40]
S. caryophyllatum	Vietnam	Leaf	Hydro-distillation	GC-MS (HP-5)	40 (97.66%)	Sesquiterpene hydrocarbons (72.73%)	β-Caryophyllene (42.53%), (*E*)-β-ocimene (19.38%), α-humulene (5.37%)
	India	Leaf	Hydro-distillation	GC-MS (HP-5)	24 (89.7%)	Oxygenated sesquiterpene (59.5%)	δ-Cadinol (42.0%), 9-*epi*-β-caryophyllene (13.4%), selin-11-en-4α-ol (5.4%) [41]

Continua Tabella II

Species	Locality	Part	Extraction	Method	Total components %	Major groups %	Major components %
		Leaf	Hydro-distillation	GC-MS (CP-Sil-8CB)	8 (80.2%)	Sesquiterpene hydrocarbons (57.5%)	β-Caryophyllene (32.4%), 1-*epi*-cubenol (11.8%), δ-cadinene (10.0%) [42]
		Leaf	Hydro-distillation	GC-MS (Omega Wax-250)	129 (99.98%)	-	α-Cadinol (18.30%), myristicin (12.02%), caryophyllene oxide (10.72%), α-pinene (10.55%), 4,8,13-duvatriene-1,3-diol (10.44%) [43]
	Pakistan	Leaf	Steam distillation	GC-MS (DB-5)	8 (99.99%)	-	Caryophyllene (96.42%) [44]
S. lanceolatum	India	Leaf	Hydro-distillation	GC-MS (HP-5)	18 (96.3%)	-	Phenyl propanal (18.3%), β-caryophyllene (12.8%), α-humulene (14.5%), caryophyllene oxide (10.7%) [45]
		Leaf	Hydro-distillation	GC-MS (CP-Sil-8CB)	21 (91.5%)	Sesquiterpene hydrocarbons (55.8%)	α-Humulene (23.1%), β-caryophyllene (16.1%), phenyl propanal (13.5%) [42]
S. lineatum	Vietnam	Leaf	Hydro-distillation	GC-MS (HP-5)	32 (96.91%)	Sesquiterpene hydrocarbons (88.26%)	β-Caryophyllene (64.53%), α-pinene (6.14%) [40]
S. kanarense	India	Aerial	Hydro-distillation	GC-MS (BP-1)	52 (91.9%)	Sesquiterpene hydrocarbons (49.5%)	Seychellene (7.3%), α-muurolol (5.4%), *cis*-cadinene ether (5.3%), β-vetivenene (5.1%),10 *epi*-γ-eudesmol (4.8%), guaiol (4.5%) [46]
S. polyanthum	Malaysia	Leaf	Hydro-distillation	GC-MS (DB-1)	18 (61.69%)	Oxygenated sesquiterpene (53.91%)	*trans*-Nerolidol (30.87%), farnesol (6.23%), α-cadinol (5.58%) [47]
		Stem	Hydro-distillation	GC-MS (DB-1)	23 (56.78%)	Oxygenated sesquiterpene (42.80%)	Cubenol (14.15%), *n*-hexadecanoic acid (11.20%), α-cadinol (6.92%) [47]
	Indonesia	Leaf	Hydro-distillation	GC-MS (ZBHP-5)	27 (99.99%)	-	*cis*-4-Decanal (43.48%), 1-decyl aldehyde (19.75%), capryl aldehyde (14.09%) [18]
S. grande	Vietnam	Leaf	Hydro-distillation	GC-MS (HP-5)	22 (91.4%)	Sesquiterpene hydrocarbons (52.9%)	β-Caryophyllene (25.6%), sabinene (16.8%), (*E*)-β-ocimene (11.9%), α-copaene (5.0%) [48]
		Stem	Hydro-distillation	GC-MS (HP-5)	44 (88.4%)	Sesquiterpene hydrocarbons (54.0%)	β-Caryophyllene (29.3%), sabinene (10.2%), (*E*)-β-ocimene (9.5%), δ-cadinene (6.6%) [48]
	India	Leaf	Hydro-distillation	GC-MS (DB-5)	30 (99.0%)	Sesquiterpene hydrocarbons (69.24%)	β-Caryophyllene (18.38%), 10s,11s-himachala-3(12),4-diene (12.06%), aromadendrene (10.51%), α-caryophyllene (10.22%), α-selinene (8.94%), δ-cadinene (6.49%) [49]

Continua Tabella II

Species	Locality	Part	Extraction	Method	Total components %	Major groups %	Major components %
S. sterrophyllum	Vietnam	Leaf	Hydro-distillation	GC-MS (HP-5)	38 (97.1%)	Monoterpene hydrocarbons (42.0%)	α-Pinene (35.4%), (*E*)-nerolidol (30.4%) [48]
S. jambos	Egypt	Leaf	Hydro-distillation	GC-MS (TGS-MS)	24 (92.00%)	-	δ-Cadinene (10.85%), cumaldehyde (10.75%), β-himachalene (6.40%), isocaryophyllene (6.39%), β-cedrene (5.63%) [50]
S. aqueum	Germany	Leaf	Hydro-distillation	GC-MS (ZB-5)	84 (90.53%)	Sesquiterpene hydrocarbons (53.13%)	α-Selinene (13.85%), β-caryophyllene (12.72%), β-selinene (11.94%), cuminyl aldehyde (9.82%) [27]
S. zeylanicum	India	Leaf	Hydro-distillation	GC-MS (HP-5)	18 (93.90%)	-	α-Humulene (37.85%), β-elemene (10.70%) [51]
		Leaf	Hydro-distillation	GC-MS (CP-Sil-8CB)	12 (97.7%)	Oxygenated sesquiterpenes (59.5%)	β-Caryophyllene (11.1%), α-cadinol (12.2%), humulene epoxide II (17.6%), caryophyllene oxide (18.9%), α-humulene (14.0%) [42]
S. arnottianum	India	Leaf	Hydro-distillation	GC-MS (CP-Sil-8CB)	21 (82.8%)	Oxygenated sesquiterpenes (58.2%)	Caryophyllene oxide (15.4%), selina-11-en-4α-ol (13.0%) [42]
S. hemisphericum	India	Leaf	Hydro-distillation	GC-MS (CP-Sil-8CB)	21 (98.7%)	Sesquiterpene hydrocarbons (84.2%)	β-Caryophyllene (40.5%), α-humulene (39.7%) [42]
S. laetum	India	Leaf	Hydro-distillation	GC-MS (CP-Sil-8CB)	10 (72.2%)	Sesquiterpene hydrocarbons (42.6%)	(*Z,E*)-α-Farnesene (21.5%), γ-amorphene (12.1%), *epi*-α-cadinol (10.2%) [42]
S. alternifolium	India	Leaf	Hydro-distillation	GC-MS (CP-Sil-5 CB)	25 (99.0%)	Monoterpene hydrocarbons (53.53%)	β-Myrcene (24.04%), β-pinene (9.23%), *trans*-β-ocimene (9.20%), cyclofenchene (7.21%) [28]
S. malaccense	Nigeria	Leaf	Hydro-distillation	GC-MS (CP-Sil-5 CB)	23 (97.0%)	-	Limonene (48.8%), γ-terpinene (26.2%) [29]
		Leaf	Hydro-distillation	GC-MS (HP-5, HP-Innowax, Cydex-B)	37 (91.8%)	Monoterpene hydrocarbons (41.6%)	*p*-Cymene (13.5%), caryophyllene oxide (8.8%), β-pinene (8.0%), α-terpineol (7.5%), α-pinene (7.3%), terpinen-4-ol (5.5%), γ-terpinene (5.0%) [52]
S. benthamianum	India	Leaf	Hydro-distillation	GC-MS (DB-5)	63 (99.63%)	-	Sitosteryl acetate (11.83%), stigmastan-3,5,22-trien (7.00%), 2,6-dimethyl-2-octene (6.99%), estra-1,3,5(10)-trien-17-β-ol (6.30%) [53]
S. densiflorum	India	Leaf	Hydro-distillation	GC-MS (DB-5)	84 (99.0%)	Sesquiterpene hydrocarbons (28.37%)	β-Maaliene (17.43%), isoledene (12.46%), α-gurjunene (10.44%), β-elemene (9.90%), β-vatirenene (8.50%), α-panasinsen (5.95%), 8,9-dehydrocycloisolongifolene (5.59%) [54]

Continua Tabella II

Species	Locality	Part	Extraction	Method	Total components %	Major groups %	Major components %
S. cordatum	South Africa	Leaf	Hydro-distillation	GC-MS (DB-5)	60 (79.0%)	-	6,10,14-Trimethylpentadecane-2-one (14.4%), 2,3-butanediol diacetate (13.3%), *n*-hexadeconic acid (7.2%), 2-chloro-1,1-*bis*(2-chloroethoxy)ethane (6.2%) [55]
S. gardneri	India	Leaf	Hydro-distillation	GC-MS (SE-30)	20 (88.8%)	Oxygenated sesquiterpenes (65.6%)	Caryophyllene oxide (49.6%), β-caryophyllene (5.3%), humulene epoxide (5.6%) [56]
S. travancoricum	India	Leaf	Steam distillation	GC-MS (HP-5)	-	-	*trans*-β-Ocimene (44.7%), *trans*-β-caryophyllene (32.9%), α-humulene (6.7%), nerolidol (8.1%) [57]
S. paniculatum	South Africa	Aerial	Hydro-distillation	GC-MS (HP-5)	75 (96.73%)	-	α-Pinene (33.13%), *n*-hexadecanoic acid (19.14%), limonene (14.26%), farnesol (14.21%), β-ocimene (13.04%), citronellol (12.67%), linoleic acid (11.50%), octahydro-1,4-dimethyl azulene (11.57%), citral (9.91%) [58]

South Africa. The extraction of the essential oils was done mostly from the leaf part. And also, the fruit, stem, and aerial part were also investigated. *Syzygium cumini* gave the highest percentage that contributed to about 100% of total oil [33]. Meanwhile, *S. caryophyllatum* showed the highest total components that comprise 129 chemical components [43]. The analysis of the chemical components identified in *Syzygium* essential oils shows that the oil consists of several groups of components, which are monoterpene hydrocarbons, oxygenated monoterpenes, sesquiterpene hydrocarbons, and oxygenated sesquiterpenes. Besides, oxygenated diterpenes, aldehydes, alcohols, ketones, and alkanes were also identified. Table II shows the major components identified in several *Syzygium* essential oils from various origins.

The major components of *Syzygium* essential oils mainly consist of sesquiterpene hydrocarbons. Ten *Syzygium* species identified sesquiterpene hydrocarbons as their major group components. Caryophyllene was identified as the major component of six *Syzygium* species, which are *S. cumini* (Brazil) [16], *S. caryophyllatum* (Vietnam) [40, 42], *S. lineatum* (Vietnam) [40], *S. grande* (Vietnam) [48], *S. zeylanicum* (India) [42], and *S. hemisphericum* (India) [42]. Other sesquiterpene hydrocarbons were also identified which are germacrene D [27], α-gurjunene (Singh et al., 2014), γ-guaiene [40], α-humulene [42, 51], seychellene [46], δ-cadinene [50], α-selinene [27], and β-maaliene [54]. Oxygenated sesquiterpenes were also characterised in several *Syzygium* essential oils. Besides, seven oxygenated sesquiterpenes were identified as the major contributors to the oil with the presence of viridiflorol (*S. samarangense*) [28], α-cadinol (*S. samarangense*, *S. cumini, S. caryophyllatum*) [29, 31, 43], fenchol (*S. cumini*) [11], t-cadinol (*S. cumini*) [15], δ-cadinol (*S. caryophyllatum*) [41], *trans*-nerolidol (*S. polyanthum*) [47], caryophyllene oxide (*S. arnottianum* and *S. gardneri*) [42, 56], and cubenol (*S. polyanthum*) [47]. Meanwhile, monoterpene hydrocarbons were characterised by the presence of high concentrations of a- and β-pinene. a-Pinene was detected in *S. cumini* [30, 31, 33-38], *S. sterrophyllum* [48], and *S. paniculatum* [58], whereas β-pinene was identified from *S. samarangense* [24, 25]. Other monoterpenes were also characterised by *Syzygium* essential oils in a large proportion, which are o-cymene [26], ocimene [24, 25], terpinolene [26], β-myrcene [28], limonene [29], and (*E*,*Z*)-α-farnesene [42].

5. BIOLOGICAL ACTIVITIES OF *SYZYGIUM* ESSENTIAL OILS

The literature study reveals that *Syzygium* essential oils have been reported in various biological activities mainly for antioxidant [11, 28, 31, 32, 38, 43, 58, 59, 60], antibacterial [11, 33, 38, 43, 59, 61] and antimicrobial [18, 28, 44, 49] activities. In antioxidant

Table III - Biological activities of *Syzygium* essential oils

Bioactivities	Essential oils	Description
Antioxidant	*S. cumini*	The leaf oil showed DPPH radical scavenging with IC_{50} value 1.2 mg/mL [11]
		The fruit oil showed high DPPH radical scavenging with IC_{50} value 219 µg/mL [31]
		The leaf oil showed DPPH radical scavenging with IC_{50} value 357 µg/mL [31]
		The fruit oil showed strong activity against FRAP and DPPH assay with IC_{50} values 8.1 µmol/g and 236 g/mL, respectively [32]
		The leaf oil showed DPPH radical scavenging with IC_{50} value 76.40 µg/mL [59]
		The leaf oil showed weak activity against FRAP with 0.47 µg/100 mg, while DPPH assay with inhibition percentage of 55.87% [38]
	S. alternifolium	The leaf oil showed significant DPPH scavenging activity with percentage inhibition 90% [28]
	S. samarangense	The leaf oil exhibited strong concentration dependent DPPH scavenging activity with percentage inhibition 90% [28]
	S. caryophyllatum	The leaf oil in winter and summer seasons showed high DPPH radical scavenging with percentage inhibition 85.83% and 83.36%, respectively [43]
	S. densiflorum	The leaf oil showed moderate activity against DPPH radical scavenging with percentage inhibition 32.09-49.74% [60]
	S. paniculatum	The summer stem-bark oil showed weak DPPH radical scavenging with IC_{50} value 0.11 µg/mL [58]
Antibacterial	*S. cumini*	The leaf oil showed activity against *Streptococcus pyogenes* and *Escherichia coli* with MIC values 1.1 and 2.1 mg/mL, respectively [11]
		The leaf oil showed activity *Streptococcus mutans, S. mitis, S. sanguinis, S. sobrinus, S. salivarius, Actinomyces naeslundii*, *Bacillus fragilis, B. thetaiotaomicron, P. nigrescens* and *P. gingivalis*, each with MIC values lower than 10 µg/mL [33]
		The leaf oil showed pronounced activity against *Bacillus cereus, Enterobacter faecalis, Salmonella paratyphi, Escherichia coli, Proteus vulgaris, Pseudomonas aeruginosa, Serratia marcescens, Staphylococcus aureus* and *Klebsiella pneumonia* with inhibition zone of 28-48 mm [59]
		The leaf oil showed moderate inhibition zones against *Escherichia coli, Staphylococcus aureus, Pseudomonas aeruginosa, Neisseria gonorrhoeae, Bacillus subtilis, Staphylococcus aureus* and *Enterococcus faecalis* with a range of 12–14 mm [38]
		The leaf oil showed good activity against *Samonella typhimurium* with zone of inhibition 20 mm [61]
	S. caryophyllatum	The leaf oil collected from winter and summer seasons showed MIC value against *Aerococcus viridans* (5.6 and 22.5 µg/mL), *Bacillus cereus* (22.5 and 5.6 µg/mL) and *Staphylococcus aureus* (11.2 and 22.5 µg/mL) [43]
	S. travancoricum	The leaf oil showed moderate activity against *Staphylococcus aureus* and *Samonella typhimurium* with zone of inhibition of 20 mm [61]
Antifungal	*S. cumini*	The leaf oil showed strong activity against *Aspergillus flavus* with MIC value 0.083 mg/mL [11]
		The leaf oil showed pronounced activity against *Alternaria alternate* with EC_{50} value 115 mg/L [37]
Antimalarial	*S. cumini*	The leaf oil showed weak activity against Heme Biocyrstallization assay with IC_{50} value 15.25 mg/mL [11]
Acetylcholinesterase	*S. cumini*	The leaf oil showed weak activity against AChE enzyme with percentage inhibition 19.97 mg/mL [26]
	S. samarangense	The leaf oil showed weak activity against AChE enzyme with percentage inhibition 13.78 mg/mL [26]
Antileishmanicidal	*S. cumini*	The leaf oil showed affected promastigote growth against *Leishmania amazonensis* with MIC value 8.78 µg/mL [33]
		The leaf oil showed minimal activity against *Leishmania amazonensis* with IC_{50} value 60 mg/L [35]

Continua Tabella III

Bioactivities	**Essential oils**	**Description**
Cytotoxicity	*S. cumini*	The leaf oil showed highest value against lung fibroblasts cell line with MIC value 679 µg/mL [33]
	S. polyanthum	The oil did not showed any significant cell injury [47]
Larvicidal	*S. lanceolatum*	The leaf oil showed high acute toxicity activity against *Anopheles stephensi* (LC_{50} 51.20 µg/mL), *Aedes aegypti* (LC_{50} 55.11 µg/mL), *Culex quinquefasciatus* (LC_{50} 60.01 µg/mL), *Anopheles subpictus* (LC_{50} 61.34 µg/mL), *Aedes albopictus* (LC_{50} 66.71 µg/mL), and *Culex tritaeniorhynchus* (LC_{50} 72.24 µg/mL) larvae [45]
	S. zeylanicum	The leaf oil exhibited significant activity against *Anopheles subpictus*, *Aedes albopictus* and *Culex tritaeniorhynchus* with LC_{50} values 83.11, 90.45, and 97.96 µg/mL, respectively [51]
Oviposition deterrent	*S. lanceolatum*	The leaf oil showed effective activity as oviposition deterrent against *Culex tritaeniorhynchus* with percentage effective repellency 92.97% [45]
Toxicity	*S. lanceolatum*	The leaf oil showed low activity against *Anisops bouvieri*, *Diplonychus indicus*, *Gambusia affinis* and *Poecilia reticulate* with LC_{50} ranging between 4148 and 15,762 µg/mL [45]
	S. cumini	The leaf oil showed weak activity against *Sitophilus oryzae* and *Tribolium castaneum* with LC_{50} value greater than 50 mg/L [36]
		The leaf oil showed low contact against *Sitophilus oryzae* with LC_{50} value higher than 0.6 mg/cm^2, while against *Tribolium castaneum* with LC_{50} value 0.41 mg/cm^2 [36]
Genotoxicity	*S. polyanthum*	The leaf and stem oils had no detachable or comet tail [47]
Antimicrobial	*S. polyanthum*	The leaf oil showed strongly inhibited activity against *Bacillus subtilis* growth with MIC value 31.25 µg/mL [18]
	S. alternifolium	The leaf oil showed strongly inhibited against *Candida rugosa*, *Bacillus subtilis* and *Staphylococcus aureus* with lowest value of MIC (0-2 mg/mL) [28]
	S. samarangense	The leaf oil showed strongly inhibited towards *Candida rugosa* and *Escherichia coli* with lowest value of MIC (0-2 mg/mL) [28]
	S. caryophyllatum	The leaf oil showed good activity against *Aspergillus niger, Aspergillus fumigatus* and *Pencillium digitatum* with inhibition zones were 20 mm [44]
	S. grande	The leaf oil showed high activity against *Escherishia coli, Pseudomonas aeroginosa, Klebsiella pneumonia, Proteus vulgaris, Staphylococcus aureus* and *Bacillus subtilis* with MIC values 0.5, 0.25, 0.25, 0.5, 0.75, and 0.5 mg/mL, respectively [49]
α-Amylase	*S. cumini*	The fruit oil showed mild activity with IC_{50} value more than 1000 µg/mL [31]
		The leaf oil showed mild activity with IC_{50} value more than 1000 µg/mL [31]
Anti-inflammatory	*S. cumini*	The leaf oil showed effectively activity on inhibited eosinophil migration with percentage inhibition of 67% [34]
Molluscicidal	*S. cumini*	The leaf oil showed highest activity against *Biomphalaria glabrata* with LC_{50} value of 90 mg/L [35]

activity, 2,2-diphenyl-1-picrylhydrazyl (DPPH radical scavenging capacity assay), ferric reducing (FRAP) assay, Trolox equivalent antioxidant capacity (TEAC or ABTS) assay, copper reduction (CUPRAC) assay, and reducing power assay (RP) have been reported. In DPPH radical scavenging capacity, the leaf oil of *S. cumini* [11] and stem bark oils of *S. paniculatum* [58] gave the strong activity with IC_{50} values of 1.2 mg/mL and 0.11 µg/mL, respectively. İn addition, the leaf oils of *S. alternifolium* and *S. samarangense* gave the highest percentage inhibition with 90% [28]. Meanwhile, the leaf oil of *S. cumini* indicated a strong activity against *Streptococcus pyogenes* and *Escherichia coli* with MIC values of 1.1 and 2.1 mg/mL, respectively [11]. İn another study, the leaf oil of *S. polyanthum* showed strong activity against *Bacillus subtilis* with MIC value 31.25 µg/mL [18]. Other bioactivity studies were also reported and are antifungal [11, 37], antimalarial [11], acetylcholinesterase [26], antileishmanicidal [33, 35], cytotoxicity [33, 47], larvicidal [45, 51], oviposition deterrent [45], toxicity [45, 36], genotoxicity [47], α-amylase [31], anti-inflammatory [34], and molluscicidal [35] activities. Table III describes the details of these activities.

6. CONCLUSION

In this article, we reviewed the relevant literature to congregate the medicinal uses, chemical composition, and bioactivities information on the *Syzygium* essential oils. According to the study, analysis of the essential oil of *Syzygium* species revealed a high content of α-pinene, β-caryophyllene, and α-cadinol. There are variations between different species and between the same species with a different origin. Further pharmacological investigations into other pharmacological activities should be performed to unravel the full therapeutic potential of the *Syzygium* species. Furthermore, preclinical analyses, as well as clinical trials as conducted for essential oils from other species, are required to evaluate the potential of essential oils from the *Syzygium* species for drug development.

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