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Mohd Aleem
Department of Pharmacology, National Institute of Unani Medicine, Kottigepalya Magadi Main Road, Bangalore, Karnataka, India

Md Imran Khan
Department of Pharmacology, National Institute of Unani Medicine, Kottigepalya Magadi Main Road, Bangalore, Karnataka, India

Fayyaz Ahmad Shakshaz
Department of Pharmacology, National Institute of Unani Medicine, Kottigepalya Magadi Main Road, Bangalore, Karnataka, India

Nusra Akbari
Department of Pharmacology, National Institute of Unani Medicine, Kottigepalya Magadi Main Road, Bangalore, Karnataka, India

Daraksha Anwar
Department of Pharmacology, National Institute of Unani Medicine, Kottigepalya Magadi Main Road, Bangalore, Karnataka, India

Corresponding Author:
Mohd Aleem
Department of Pharmacology, National Institute of Unani Medicine, Kottigepalya Magadi Main Road, Bangalore, Karnataka, India

Botany, phytochemistry and antimicrobial activity of ginger (*Zingiber officinale*): A review

Mohd Aleem, Md Imran Khan, Fayyaz Ahmad Shakshaz, Nusra Akbari and Daraksha Anwar

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Abstract
Antibiotic resistance in every corner of the planet is growing to dangerously high levels. New mechanisms of resistance are emerging and spreading globally which threatens our ability to treat common infectious diseases. Many scientists documented some plants having antimicrobial properties. *Zingiber officinale* Roscoe (*ZO*), the most recognised member of Zingiber, is one of them. This review aims to validate the antimicrobial activity of ginger. The information and data on ZO were collated from various resources like ethnobotanical textbooks, Pub Med, Google Scholar, Science Direct, Web of Science, and Scopus. *ZO* has many medicinal, nutritional and ethnomedical values and is commonly used as a spice, flavouring agent and herbal remedy worldwide. In addition to giving ginger its pungent aroma, volatile oil gingerol and other pungent principles are the most medically potent since they inhibit the production of prostaglandin and leukotriene, which are chemicals that affect blood flow and inflammation. Traditionally, it has been used as an herbal remedy for centuries in Ayurvedic, Tibb-Unani, Chinese, Islamic, Africans, the Caribbean and many other medicinal systems to cure a variety of diseases like throat infections, asthma, inflammation, dyspepsia, loss of appetite, palpitation, constipation and indigestion, colds, arthritis, nausea, hypertension, migraines, and many more. It has a high proportion of α-Zingiberene, β-sesquiphellandrene, (E,E)- α-farnesene, geranial and ar-curcumene**.** The ZO extracts, essential oil and chemical constituents exhibited antimicrobial, anticonvulsant, analgesic, anti-inflammatory, antiulcer, immunomodulatory, and other beneficial activities. The research suggests that there are marked antimicrobial activities in the ginger that could be beneficial and applied in various research areas, such as the pharmaceutical and food industries. To understand the molecular mechanisms by which these effects are exerted, more research may be required.

Keywords: Ginger, *Zingiber officinale*, antimicrobial, terpenes, zingiberene

1. Introduction
In 1911, Salvarsan and its derivative neoarsphenamine were used against syphilis as the first antimicrobial drugs successfully used against life-threatening infectious diseases. This breakthrough, which transformed the definition of drug therapy, was named the "magic bullet," and the word "chemotherapy" was introduced [1]. After the Golden Age revolution, when virtually all necessary antibiotics were discovered, and the main chemotherapy problems were solved in the 1960s, history is now repeating itself. These exciting compounds are at risk of losing their potency due to increased microbial resistance [2]. Antibiotic resistance in every corner of the planet is growing to dangerously high levels. New mechanisms of resistance are emerging and spreading globally, threatening our ability to treat common infectious diseases. As antibiotics become less successful, a rising list of infections such as pneumonia, tuberculosis, blood poisoning, gonorrhoea, and foodborne diseases are becoming more complicated and even impossible to treat [3, 4]. Consequently, there is an urgent need to find an alternative to chemotherapy drugs, especially those of plant origin, which are readily available and have substantially fewer side effects in treating diseases. The use of higher plants and their extracts in many parts of the world has long been practiced to treat infectious diseases [5, 6].
Since the late 19th century, scientific studies have reported the antimicrobial existence of individual spices, herbs, and their components. Approximately 80 per cent of the world's population currently depends on botanical preparations as medicines to meet their health needs. Fortunately, it is not clear that even long-term use of these substances would cause any side effects. Since ancient times they have been widely used in many countries of Asia and Africa. However, in recent years, the use of spices/herbs in developing countries has also steadily increased because of their beneficial effects [7, 8].
Many scientists documented some plants having antimicrobial properties. *Zingiber officinale* is one of them [9]. It has many medicinal, nutritional, and ethnomedical values and is commonly used as a spice, flavouring agent, and herbal remedy worldwide [10].

In addition to giving ginger its pungent aroma, volatile oil (gingerol) and other pungent principles are the most medically potent [9]. The characteristic odour and taste of ginger are caused by a mixture of non-volatile pungent compounds such as zingerone, shogaols, and gingerols [11]. Ginger rhizome is one of the world's best-known spices and has been used for its health benefits in complementary medicine dates back 2,500 years [12]. It is cultivated in China, Nepal, India, Bangladesh, United States, Taiwan, Jamaica, Nigeria, and Indonesia. The principal producers and exporters are India and China. It has been used in Ayurvedic, Tibb-Unani, Chinese, Islamic, Africans, the Caribbean, and many other medicinal systems to cure a variety of diseases like throat infections, asthma, inflammation, palpitation, constipation, indigestion, arthritis, hypertension, migraines, and many more [10, 13, 14]. Ginger is a food spice that also has been accepted by the American Diabetic Association as a nutraceutical. Nutraceutics are functional foods that provide essential health benefits, including disease prevention and treatment [15].

In recent decades, *ZO* has been extensively investigated by advanced scientific techniques for medicinal properties, and many bioactive compounds have been isolated from various parts of the plant [16]. It has a high proportion of α-Zingiberene, β-sesquiphellandrene, (E,E)- α-farnesene, geranial, and ar-curcumene [15]. Its extracts and active compound exhibited antimicrobial, anticonvulsant, analgesic, anti-inflammatory, antiulcer, gastric antisecretory, antidiabetic, nephroprotective, hepatoprotective, antitumor, anticancer, antispasmodic, antithrombotic, hypocholesterolemic, antiallergic, antiserotonergic, anticholinergic, antioxidant, larvicidal, immunomodulatory activities and other beneficial activities [16, 17]. Also, gingerol and its derivatives are recognised as promising potential cancer-preventive and anticancer agents [18].

2. Material and methods

A systematic ginger-related literature quest was carried out to collect all relevant information on common uses, phytochemicals, and pharmacological activities. Publicly available databases and primary sources, including PubMed, SciFinder, Web of Science, Science Direct, PhD dissertations, have been scanned. A large number of literature articles published from 2001 to 2019 were reviewed. Searching for regarding the information on the ginger was carried out by using Latin names, *Zingiber officinale* Roscoe, and vernacular names as Zanjabil, Ginger, and Sonth. The extracted data included isolated compounds and antimicrobial activity. The name of species has been validated using 'The Plant List' (www.theplantlist.org). All chemical structures images were taken from PubChem.

3. Vernacular names

Arabic: Zanjabil; China: Gan-Jiang (dried), Shēng jiāng (fresh); Dutch: Gember; English: Ginger; French: Gingembre; German: Ingwer; Greek: Piperoriza; Japan: Shouga; Nepal: Agnimanth, Sutho; Persian: Amveel, Zanjabil; Russian: Imbir; Spanish: Jengibre; Sanskrit: Adraka (Fresh), Shunthi (Dried), Shringaveran; Urdu and Hindi: Adrak (fresh), Sonth (dry) [19-21].

4. Botany

The genus Zingiber, belonging to the family Zingiberaceae, comprises about 85 species of herbs, mostly grown in Asia, South, Central America, and Africa [13]. Zingiber officinale Roscoe is the accepted name of a species in the genus Zingiber. It is a tropical plant that grows well in hot and humid climates. There are three known ginger types: giant ginger or white ginger (Zingiber officinale var. Roscoe), small white ginger, (Zingiber officinale var. Amarum), and red ginger (Zingiber officinale var. Rubrum). Zingiber officinale Roscoe is one of the most commonly used herbs in Asia, has been empirically used to treat various disorders [16].

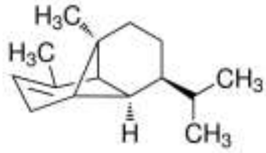
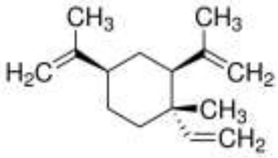
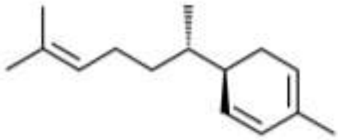
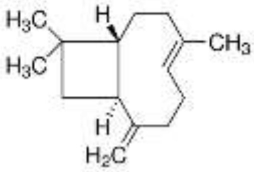
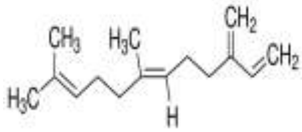
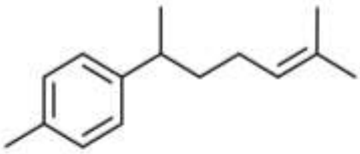
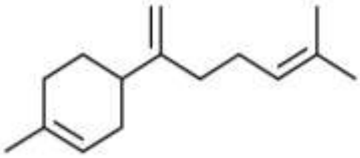
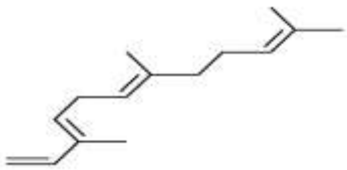
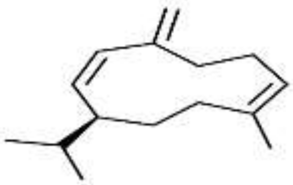
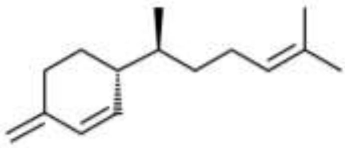
It is a perennial, herbaceous plant that grows up to a height of about 100 cm. The leaves develop from the branched rhizome [11]. Leaves are simple, alternate, distichous narrow oblong-lanceolate, 2-3 cm broad with sheathing bases, the blade gradually tapering to point. The inflorescence is solitary, lateral radical pedunculate oblong cylindrical spikes. Flowers are rare, which resemble the orchids, consisting of several overlapping scales on an elongated stalk. Each flower has three yellowish-orange petals with an additional purplish, lip-like structure. Rhizomes are aromatic, thick lobed, pale yellowish. The herb develops several lateral shoots in clumps, which begin to dry when the plant matures [11, 13].

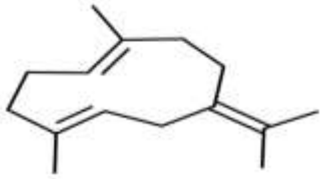
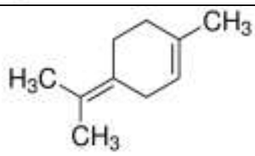
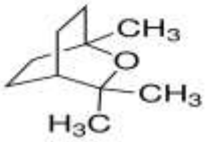
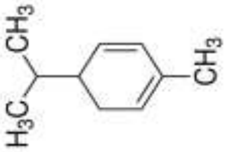
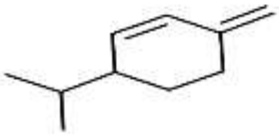
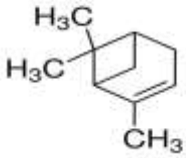
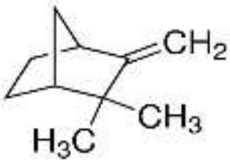
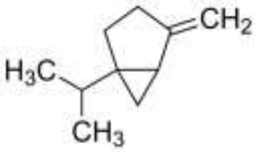
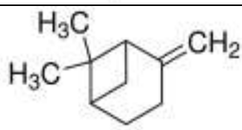
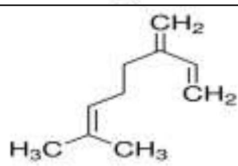
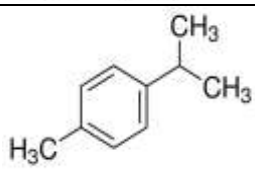
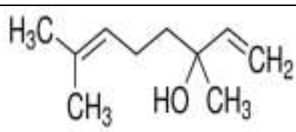
5. Chemical constituent

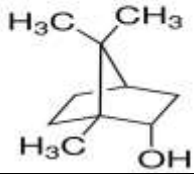
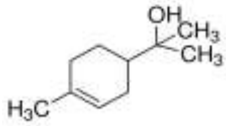
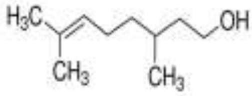
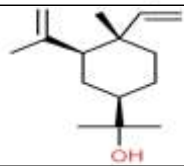
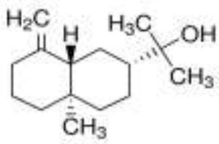
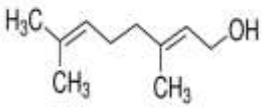
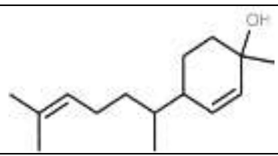
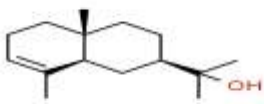
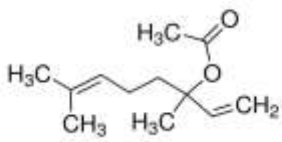
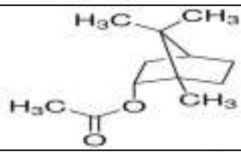
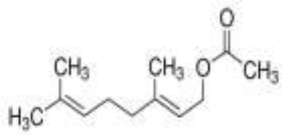
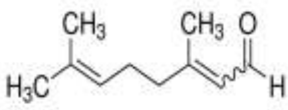
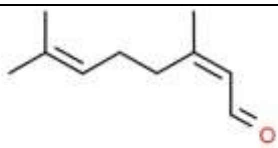
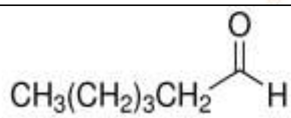
The chemical compounds found in ginger rhizome was identified by gas chromatography-mass spectrometry, gas chromatography with flame ionisation detection, high-performance liquid chromatography, and liquid chromatography-mass spectrometry. Gas chromatography helps detect volatile compounds with low molecular weight, whereas liquid chromatography has distinguished polar compounds [22]. The powdered ginger sample's nutritional composition consists of carbohydrates, protein, fat, dietary fibre, iron, calcium, vitamin C, and carotene [23]. The main components of ginger rhizome are essential oils, terpenes (zingiberene, beta-bisabolene, alpha-farnesene, beta-sesquiphellandrene, alpha-curcumene) Table 1, phenol compounds (gingerol, shogaol, paradols etc.) Table 2 and flavonoid compounds (Luteolin, rutin etc.) Table 3 [16, 23]. Flavonoids and phenolic compounds are the most common secondary metabolites in plants and are found in food and nutraceutical products [16].

Ginger contains essential oils and oleoresins, which create a robust, sour, and pungent flavour [22]. The most important compounds responsible for ginger's medicinal activities are classified into non-volatile and volatile compounds [11, 16]. The three main groups of compounds present in volatile oils were monoterpenoids, sesquiterpenoids, and aldehydes responsible for ginger's sensory characteristics [22, 24]. The sesquiterpene derivatives (-)- zingiberene, (+)-curcumene, (-)-β-sesquiphelandrene, and β-bisabolene are responsible for the aroma [16]. Camphene has a terpeney camphoraceous taste, while sabinene has a hot, oily-peppery, and a slightly pungent spicy taste. α-Curcumene has a distinctive turmeric odour and a mildly pungent bitter taste. Zingiberene has a warm, woody-spicy, and very persistent odour, while α-farnesene has a very mild, sweet, and warm odour. Neral and geranial are commonly used as a strong lemon fragrance chemical [24]. Non-volatile phenylpropanoid-derived compounds, particularly gingerols, shogaols, paradols, and zingerone, are responsible for the pungent taste [11, 16, 22]. Oleoresins derived from various solvents include eugenol, zingerone, trans-6-shogaol, and geranial as the main compounds [22]. The elements responsible for the spicy taste of ginger have been known as gingerols [16]. Zingerone developed from gingerols during drying or cooking is responsible for the warm pungent sensation in the mouth and many of the pharmacological effects of the plant are also recorded [11].

Table 1: Classification and structure of chemical constituent of *ZO*

S. No	Classification	Chemical compounds	Structure	References
1		α-Copaene		[8, 25–30]
2		β-elemene		[8, 25–27, 29, 31]
3		Zingiberene (α-Zingiberene)		[8, 24–27, 29, 32, 33]
4		Caryophyllene (β-Caryophyllene)		[25, 26, 28, 29]
5		β-Farnesene , trans-β-Farnesene, (E)-beta-farnesene		[8, 25-27, 29, 31]
6	Sesquiterpene	Curcumene (ar-Curcumene)		[8, 24-27, 29, 32, 33]
7		β-Bisabolene		[26, 29, 31-33]
8		E,E-α-Farnesene		[8, 25, 26, 30, 33]
9		Germacrene D		[25-28, 30]
10		β-Sesquiphellandrene		[8, 26, 27, 30, 32, 33]

11		Germacrene B		[8, 25-27, 32]
12		Terpinolene		[8, 25, 26, 28]
13		1,8-Cineole		[8, 25, 26, 30]
14		α-Phellandrene		[8, 25-28, 30]
15		β-Phellandrene		[8, 26-28, 30]
16	Monoterpenes	α-pinene		[8, 26, 27, 29, 31]
17		Camphene		[8, 24-27, 29, 31]
18		Sabinene		[8, 24, 26, 29, 31]
19		β-pinene		[8, 25-27, 29]
20		β-Myrcene		[8, 25-27, 29]
21		p-Cymene		[8, 26, 27, 30]
22	Alcohols	Linalool *Oxygenated monoterpenes*		[8, 26, 27, 29, 32]

23		Borneol		[8, 25, 27, 29, 31]
24		α-Terpineol		[8, 25-27, 29]
25		Citronellol *Oxygenated monoterpenes*		[8, 25, 26, 29, 32]
26		Elemol		[8, 25, 26, 29, 31]
27		β-Eudesmol		[8, 25-27, 29, 31]
28		Geraniol		[8, 25-27, 30]
29		Zingiberenol		[8, 26-28]
30		α-Eudesmol		[25, 26, 28]
31	Esters	Linalyl acetate		[29]
32		Bornyl acetate		[27, 29]
33		Geranyl acetate		[8, 28, 29]
34	Aldehydes	Geranial/citral *Oxygenated monoterpenes*		[8, 24, 26, 27, 29, 32, 33]
35		Neral *Oxygenated monoterpenes*		[8, 24, 26, 27, 29, 32]
36		Hexanal		[25, 26]

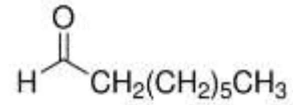
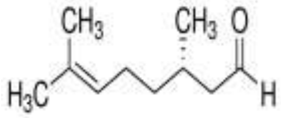
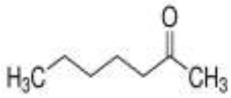
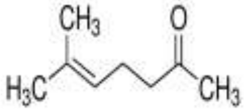
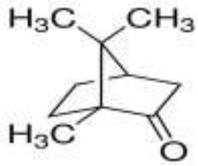
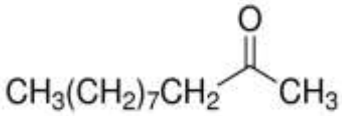
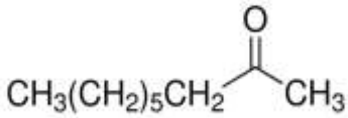
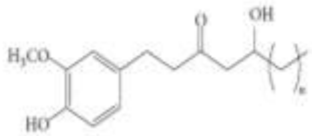
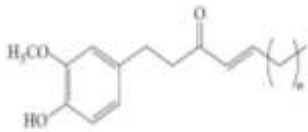
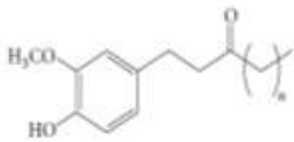
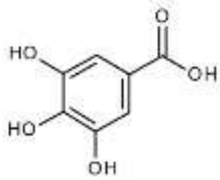
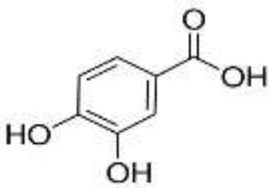
37		n-Octanal		[8, 26, 27]
38		Citronellal		[8, 26]
39	Ketone	2-Heptanone		[26, 27]
40		Sulcatone (6-Methyl-5-hepten-2-one)		[8, 26, 27]
41		Camphor		[8, 25-28]
42		2-Undecanone		[8, 26, 27]
43		2-Nonanone		[8, 27, 28]

Table 2: Phenolic compounds of ginger

S. No	Name	Structure	References
1	Gingerol ([4]-, [6]-, [7]-, [8]-, [10]- gingerol, Methyl [4]-, Methyl [6]-gingerol)		[34-37]
2	Shogaol ([4]-, [6]-, [8]-, [10]-, [12]-Shogaol, Methyl [6]-, Methyl 8]-shogaol)		[34-37]
3	Paradol ([6]-, [7]-, [8]-, [9]-, [10]-, [11]-, [13]- paradol, Methyl [6]-paradol)		[36]
4	Gallic acid		[29, 37-41]
5	Protocatechuic acid		[29, 37, 38]

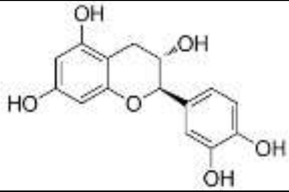
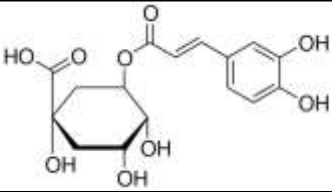
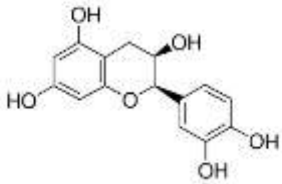
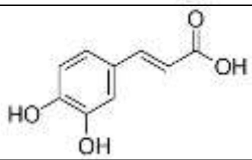
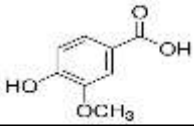
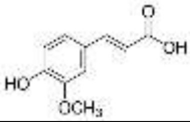
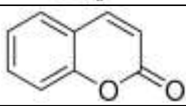
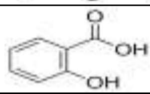
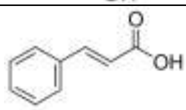
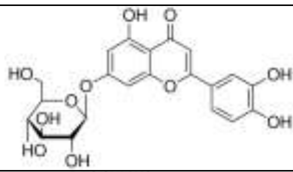
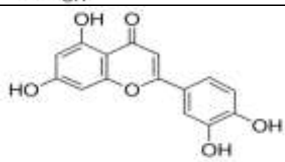
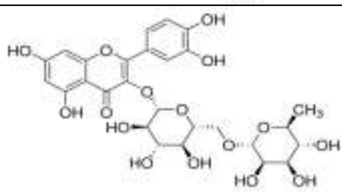
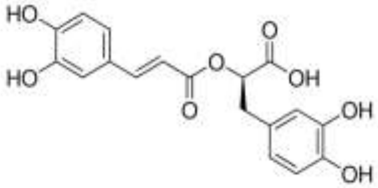
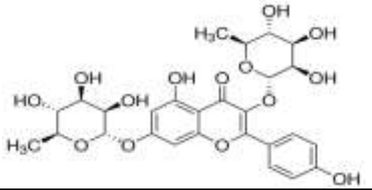
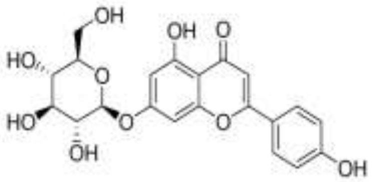
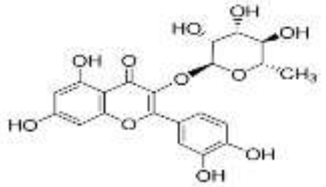
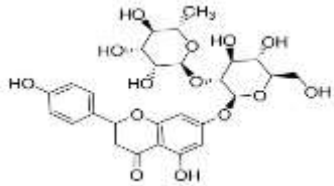
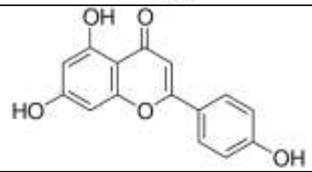
6	Catechin		[29, 37, 41, 42]
7	Chlorogenic acid		[29, 37, 43]
8	Epicatechin		[29, 37, 39]
9	Caffeic acid		[29, 37, 38, 40, 43]
10	Vanillic acid		[29, 37, 38, 40-42]
21	Ferulic acid		[29, 37, 38, 40-42]
12	Coumarin		[29, 37]
13	Salicylic acid		[29, 37, 39]
14	Cinnamic acid		[29, 37, 38, 41, 42]

Table 3: Flavonoid compounds of ginger

S. No	Name	Structure	References
1	Luteolin.7-glucoside (Cynaroside)		[29, 43]
2	Luteolin		[29, 40, 43]
3	Rutin		[29, 42, 43]

4	Rosmarinic acid		[29, 43]
5	Kaempferol 3,7-dirhamnoside (Kaempferitrin)		[29, 41, 42]
6	Apigenin 7-glucoside		[29, 43]
7	Quercetin		[29, 40-43]
8	Naringenin		[29, 42]
9	Apigenin		[29, 40]

6. Pharmacological activity

The plant is reported for antimicrobial [31], anticonvulsant [44], analgesic [45], anti-inflammatory [46], antiulcer, gastric antisecretory [47], antidiabetic [48], nephroprotective [49], hepatoprotective [29], antitumor [29], anticancer [50], antispasmodic, antithrombotic, hypocholesterolemic, antiallergic [51], antiserotonergic, anticholinergic [52], antioxidant, larvicidal, immunomodulatory [53] activities and other beneficial activities.

6.1 Antimicrobial property

Ginger shows antibacterial property against so many gram-positive and the gram-negative bacteria; (Table 4) namely, *Escherichia* (E) *coli*, *Staphylococcus* (St) *aureus*, St. *epidermidis, Klebsiella (K) pneumoniae, Enterococcus* (En) *faecalis, Salmonella* (Sl) *typhi, Sl. typhimurium, Pseudomonas* (Ps) *aeruginosa*, *Proteus* (Pr) *sp., Bacillus* (Bc) *cereus, Bc. subtilis, Bc. megaterium and Streptococcus* (S) *faecalis* [13]. Rampogu *et al.* studied that gingerenone-A and shogaol have a potential St. *aureus* encodes a unique enzyme, 6-hydroxymethyl-7,8-dihydropterin pyrophosphokinase inhibitors [54]. Noori *et al*. indicated that the nanoemulsion-loaded coating solution has potent antimicrobial activity comparable to gentamicin antibiotic[31]. According to Mostafa, 2018, volatile oil nanoemulsion formulation was stable and effective on S. *mutans* [55]. In another study, the ethanol extract showed considerable activity on Ps. aeruginosa, *Bc.* subtilis with zones of inhibition ranging from 7±0.4mm at a concentration of 6.25mg/ml to 23.0 ±3.2 mm at 100 mg/ml and MIC ranging from 6.25mg/ml to 12.5 mg/ml against *Bc.* subtilis and Candida albicans. The activity of the aqueous extract was very minimal at low concentrations, but marked activity was observed at higher concentrations [56].

In another research, the Antimicrobial potency of fresh, natural, and commercial dried *ZO* extracts had been investigated against seven local clinical bacterial isolates by the agar disc diffusion method. The result shows that ZO's chloroform and diethyl ether extracts showed a more significant inhibition zone of tested pathogens except *P. aeruginosa* and *E. coli* [57]. The Methanolic extract of *ZO* was assayed *in vitro* for antibacterial activity by using the agar diffusion method. The zone of inhibition was compared with different standard antibiotics. The result showed good antibacterial activity [58].

Table 4: Antimicrobial activity of *ZO*

S. no	Activity	Type of extract/	concentration	Components	models/method	*Tested organism*	The diameter of the inhibition zone	Minimal inhibitory Concentration (MIC)	Positive Controls	Ref.
1	Antibacterial	Silver nanoparticle	500 µg/mL to 1.95 µg/mL	-------------	Agar well diffusion assay, 96 well microtiter plate assay	*S. aureus and E. coli*	16-19 mm	62.5-125 µg/mL	---------------	[59]
2	Antibacterial	Silver nanoparticle from ginger extract	0.8–50 µg/mL	--------------	agar well diffusion method, broth dilution assay	*Vibrio (V) anguillarum, V. alginolyticus, Aeromonas punctata, V.parahaemolyticus, V. splendidus, and V. harveyi*	11.1±0.02-15.8±0.05 mm	0.4- 6.5 µg/mL	106 CFU/mL bacterial suspensions	[60]
3	Antibacterial	Leaves essential oil nano emulsion	100 µl	β-pinene (8.59%), terpinolene (7.46%), δ-Cadinene (7.05%)	Agar diffusion method, Broth microdilution method	*S. mutans ATCC 25175*	25 ± 1.0 mm	62.5 µl/mL	Clindamycin 2 µg/disc	[55]
4	Antibacterial	ethanolic	----------------	------------	*In vitro* /microdilution method	*St. aureus, Bc. subtilis, Bc. cereus, Ps.aeruginosa, Pr. mirabilis, E. coli, Sl. enterica and Sl. typhimurium*	------------	0.0024-> 20 µg/ml	Tetracycline	[61]
5	Antibacterial	Methanolic	0.78-100 µg/ml	6-,8-, 10-gingerol and 6-shogoal	*In vitro*/agar dilution method	*Helicobacter pylori*	----------	6.25–50 µg/ml	Amoxicillin	[62]
6	Antibacterial	methanolic	-----------	Octanal, 2-Naphthale Namine, Endo-Borneol, Decanal, 1,2-15,16-Diepoxyhexadecane, Propanal,2-methyl-3-phenyl, Benzeneacetic acid ,4-(1H-1,2,3,4-tetrazol-1-yl), Ascaridole epoxide etc	Muller-Hinton agar plates	*Ps.eurogenosa, E. coli, K. pneumonia, St. aureus, Pr. mirabilis*	1.99±0.200-4.93±0.290 mm	------------	Streptomycin, Rifampin, Cefotaxime	[58]
7	Antibacterial	ginger extract	0.001-0.6 mg/mL	------------	Solid blood agar culture medium	*S. mutans and S. sanguinis*	------------	0.02-0.3 mg/mL	------------	[63]
8	Antibacterial	Boiled ginger extract	---------------	----------------	Agar diffusion assay	*E. coli, Ps.aeruginosa, St. aureus, Vibrio cholerae, K. spp., and Sl. species*	8.0±1.73-11.67±1.53 mm	--------------	Gentamicin	[6]
9	Antibacterial	Essential oil	0.04-5 mg/mL	----------	Broth Microdilution Assays	*En. faecalis*	--------	0.31 mg/mL	Amoxicillin or ampicillin and 2.5% sodium hypochlorite	[64]
10	Antibacterial	Nano emulsion-based edible sodium caseinate coating containing ginger essential oil	3%, 6% of essential oil	α-zingiberene, β-sesquiphellandrene	agar well diffusion assay, paper disc method	*Listeria monocytogenes, Sl. typhimurium (ATTC 14028)*	(8.66 ± 0.94 mm and 10.33 ± 0.93 mm	------------	Chloramphenicol and gentamicin	[31]
11	Antibacterial	ethanolic extract	----------	------------	Cup- Plate Agar Diffusion Method, macro broth dilution methods	*St. aureus, Pr. mirabilis, Ps.aeruginosa, K. pneumoniae, E. coli*	17-19 mm	3.3-12.5%	---------	[65]
12	Antibacterial	Methanol extract	25-100 µg/mL	-----------	Agar-well diffusion method, broth microdilution method	*Ps.aeruginosa, K. pneumonia, Sl. typhi, St. aureus, E. coli*	15.08 ± 0.20 - 26.03 ± 0.41 mm	12.5-25 µg/mL	----------	[66]
13	Antibacterial	Methanol: Water (70: 30)	1-200 mg/ml	-----------	agar well diffusion method	*P. aeruginosa*	27.09 ± 0.003 mm	10 µg/ml	Amikacin	[67]
14	Antibacterial	Essential oil	0.0125 to 2.0 mg/mL	Eudesmol, γ-terpinene, α-curcumene, alloaromadendrene, zingiberene	disk-diffusion, agar dilution methods	*S. aureus, S. aureus, S. epidermidis, E. faecalis, E. aerogenes, E. coli, K. oxytoca, K. pneumoniae, S. enterica, S. typhi, S. marcescens*	6.33 ± 0.57-32.66 ± 2.01 mm	0.25- 2.0 µg/ml	Chloramphenicol 1 to 15 µg/mL	[12]

15	Antibacterial	Aqueous extracts	3.125-100 mg/ml	Alkaloids, saponins, tannins, flavonoids, terpenoids, phenols and steroids	Agar well diffusion method, broth microdilution method	*Bc. subtilis, Ps.aeruginosa*	19.0 ±1.20 10.0 ±0.10 mm at 100 mg/ml	12.50, 25.00 mg/ml	------------	[56]
16		ethanol extracts	3.125-100 mg/ml	Alkaloids, saponins, tannins, flavonoids, terpenoids, phenols, and steroids	Agar well diffusion method, broth microdilution method	*Bc. subtilis, Ps.aeruginosa*	23.0 ±3.20, 14.0 ±0.60 mm at 100 mg/ml,	6.25, 12.50 mg/ml,		
17	Antibacterial	Aqueous, 70% ethanol, Ethyl acetate	0.32-50, mg/ml	-----------	Well diffusion assay	*E. faecalis, S. aureus, S. epidermidis, A. baumannii*	12-16 mm	25-50 mg/ml	Vancomycin (30µg) and Amikacin (30µg)	[68]
18	Antibacterial	aqueous extract	2.5-10 (µg /ml)	Alkaloid, Anthraquinone, saponin, phenol, Flavonoid, terpenoid and glycoside, steroid and reducing sugar	Disc diffusion method	*K. pneumonia, Sl. typhi, Shigella species, S.aeruginosa, E. coli, St. aureus*	12.1±0.13-15.0±0.12 mm at 10 µg /ml	-----------	Ciprofloxacin 10 µg	[69]
19	Antibacterial	ethanol extract	2.5-10 (µg /ml)	Alkaloid, Anthraquinone, saponin, phenol, Flavonoid, terpenoid and glycoside, steroid and reducing sugar	Disc diffusion method	*K. pneumonia, Sl. typhi, Shigella species, S.aeruginosa, E. coli, St. aureus*	15.4±0.17-18.3±0.47 mm at 10 µg /ml	------------	Ciprofloxacin 10 µg	
20	Antibacterial	n-hexane extract	2.5-10 (µg /ml)	Alkaloid, Anthraquinone, saponin, phenol, Flavonoid, terpenoid and glycoside, steroid and reducing sugar	Disc diffusion method	*K. pneumonia, Sl. typhi, Shigella species, S.aeruginosa, E. coli, St. aureus*	08.8±0.17-13.3±0.11 at 10 µg /ml	----------------	Ciprofloxacin 10 µg	
21	Antibacterial	methanolic extract	-------------	endophytic actinomycetes (ZoA1, ZoA2, ZoA3, ZoA4, ZoA5, ZoA6, ZoA7, ZoA8, ZoA9, ZoA10, ZoA 11, ZoA 12, ZoA 13 and ZoA 14)	well diffusion method	*Sl. enterica typhi, St. aureus, Bc. subtilis and Vibrio cholerae*	8–14 mm- >21 mm	----------------	Ciprofloxacin Vancomycin, Gentamycin	[70]
22	Antibacterial	Fresh zinger Diethyl Ether extract	200 µl	Cardiac glycosides, flavonoids, alkaloids, tannins, saponins, and steroids	agar disc diffusion method	*E. coli, Ps.aeruginosa, K. pneumonia, St. aureus, S. pyogenes, St. epidermidis, Serratia marcesnces*	3.67±1.33-23.33±2.88 mm	------------	----------	[57]
23	Antibacterial	Fresh zinger Chloroform extract	200 µl	Cardiac glycosides, flavonoids, alkaloids, tannins, saponins, and steroids	agar disc diffusion method	*E. coli, Ps.aeruginosa, K. pneumonia, St. aureus, S. pyogenes, St. epidermidis, Serratia marcesnces*	6.00±2.64-36.33±2.08 mm	------------	------------	[57]
24	Antibacterial	Fresh zinger Ethanolic extract	200 µl	Cardiac glycosides, flavonoids, alkaloids, tannins, saponins, and steroids	agar disc diffusion method	*E. coli, Ps.aeruginosa, K. pneumonia, St. aureus, S. pyogenes, St. epidermidis, Serratia marcesnces*	2.00±1.00-15.00±1.00 mm	------------	------------	[57]
25	Antibacterial	Fresh zinger Methanolic extract	200 µl	Cardiac glycosides, flavonoids, alkaloids, tannins, saponins, and steroidas	agar disc diffusion method	*E. coli, Ps.aeruginosa, K. pneumonia, St. aureus, S. pyogenes, St. epidermidis, Serratia marcesnces*	1.33±0.58-26.33±1.58 mm	------------	------------	[57]
26	Antibacterial	Fresh zinger Aqueous extract	200 µl	Cardiac glycosides, flavonoids, alkaloids, tannins, saponins, and steroids	agar disc diffusion method	*E. coli, Ps.aeruginosa, K. pneumonia, St. aureus, S. pyogenes, St. epidermidis, Serratia marcesnces*	5.33±1.33-32.00±2.00 mm	------------	------------	[57]
27	Antibacterial	Naturally dried zinger Diethyl Ether extract	200 µl	Cardiac glycosides, flavonoids, alkaloids, tannins, saponins, and steroids	agar disc diffusion method	*E. coli, Ps.aeruginosa, K. pneumonia, St. aureus, S. pyogenes, St. epidermidis, Serratia marcesnces*	3.33±0.33-22.00±2.00 mm	------------	------------	[57]
28	Antibacterial	Naturally dried zinger. Chloroform extract	200 µl	Cardiac glycosides, flavonoids, alkaloids, tannins, saponins, and	agar disc diffusion method	*E. coli, Ps.aeruginosa, K. pneumonia, St. aureus, S. pyogenes,*	2.33±0.33-32.33±2.08 mm	------------	------------	[57]

				steroids		*St. epidermidis, Serratia marcesnces*				
29	Antibacterial	Naturally dried zinger. Ethanolic extract	200 µl	Cardiac glycosides, flavonoids, alkaloids, tannins, saponins, and steroids	agar disc diffusion method	*E. coli, Ps.aeruginosa, K. pneumonia, St. aureus, S. pyogenes, St. epidermidis, Serratia marcesnces*	0.00±0.00-35.67±2.08 mm	------------	------------	[57]
30	Antibacterial	Naturally dried zinger. Methanolic extract	200 µl	Cardiac glycosides, flavonoids, alkaloids, tannins, saponins, and steroids	agar disc diffusion method	*E. coli, Ps.aeruginosa, K. pneumonia, St. aureus, S. pyogenes, St. epidermidis, Serratia marcesnces*	2.00±1.00-27.67±2.51 mm	------------	------------	[57]
31	Antibacterial	commercially dried zinger Diethyl Ether extract	200 µl	Cardiac glycosides, flavonoids, alkaloids, tannins, saponins, and steroids	agar disc diffusion method	*E. coli, Ps.aeruginosa, K. pneumonia, St. aureus, S. pyogenes, St. epidermidis, Serratia marcesnces*	1.33±0.33-32.00±2.00 mm	------------	------------	[57]
32	Antibacterial	Commercially dried zinger. Chloroform extract	200 µl	Cardiac glycosides, flavonoids, alkaloids, tannins, saponins, and steroids	agar disc diffusion method	*E. coli, Ps.aeruginosa, K. pneumonia, St. aureus, S. pyogenes, St. epidermidis, Serratia marcesnces*	2.00±1.00-30.00±1.00 mm	------------	------------	[57]
33	Antibacterial	Commercially dried zinger Ethanolic extract	200 µl	Cardiac glycosides, flavonoids, alkaloids, tannins, saponins, and steroids	agar disc diffusion method	*E. coli, Ps.aeruginosa, K. pneumonia, St. aureus, S. pyogenes, St. epidermidis, Serratia marcesnces*	1.33±0.33-20.67±1.58 mm	------------	------------	[57]
34	Antibacterial	Commercially dried zinger. Methanolic extract	200 µl	Cardiac glycosides, flavonoids, alkaloids, tannins, saponins, and steroids	agar disc diffusion method	*E. coli, Ps.aeruginosa, K. pneumonia, St. aureus, v pyogenes, St. epidermidis, Serratia marcesnces*	2.00±1.00-30.33±1.58 mm	------------	------------	[57]
35	Antibacterial	Ethanol Extract	-------------	saponins, tannins, alkaloids and flavonoids	agar diffusion method	*St. aureus, Bc. subtilis, Pr. mirabilis, Ps.aeruginosa, E. coli, Sl. typhi*	0.00- 13.00 mm	------------	Nitrofurantoin, Augmentin, Norfloxacin, Tetracycline Gentamycin, Ciprofloxacin, Chloramphenicol, Ampicillin, Nalidixic acid, Cefuroxime, Drovid, Cephalexin, Erythromycin, Clindamycin, Septrin, Amoxil, Amplicox	[9]
36	Antibacterial	Aqueous Extract		saponins, tannins, alkaloids and flavonoids	agar diffusion method	*St. aureus, Bc. subtilis, Pr. mirabilis, Ps.aeruginosa, E. coli* and *Sl. typhi*	0.00- 17.00 mm			
37	Antifungal activity	methanolic extract	----------	Endophytic actinomycetes	well diffusion method	*Pythium myriotylum*	1-14 mm	------------		[70]
38	Antifungal activity	Aqueous	3.125-100 mg/ml	Alkaloids, saponins, tannins, flavonoids, terpenoids, phenols, and steroids	Agar well diffusion method, broth microdilution method	*Aspergillus flavus* and *Candida albicans*	18.0 ±1.30 mm	6.25 mg/ml	----------	[56]
39	Antifungal activity	ethanol extracts	3.125-100 mg/ml	Alkaloids, saponins, tannins, flavonoids, terpenoids, phenols, and steroids	Agar well diffusion method, broth microdilution method	*Aspergillus flavus* and *Candida albicans*	19±1.80 mm	6.25 mg/ml	---------	
40	Antifungal activity	Essential oil	0.0625 to 2.0 mg/mL	Eudesmol (8.19%), γ-terpinene (7.88 %), α-curcumene (7.28%), alloaromadendrene (6.56%), zingiberene (6.06 %)	inhibition of radial growth, 24-well plates for filamentous fungi,	*A. niger, F. moniliforme, F. sporotrichum* and *T. entagrophytes*	-----------	FC50 value: 0.08-1.5 mg/mL	Ketoconazole (60 µg)	[12]
41	Antifungal activity	Essential oil	0.0625 to 2.0 mg/mL	Eudesmol (8.19%), γ-terpinene (7.88 %), α-curcumene (7.28%), alloaromadendrene (6.56%), zingiberene (6.06 %)	Kirby-Bauer agar diffusion method, 24-well plates for yeast fungi,	*C. albicans17MR, C. tropicalis* and *C. glabrata*	14.50 ± 12.12 to 30.00± 0.00 mm	0.25-0.75 mg/mL	Nystatin (30 µg/disc)	[12]

7. Discussion

The study result highlights the usefulness of *ZO* in treating microbial diseases and the need to improve their utilisation in this respect. It is especially urgent when considering the growth rate of multi-resistant drug strains of bacteria increases worldwide [9]. Different *in vitro* and *in vivo* experiments were performed to determine the efficacy of essential oil, oleoresins, and extracts obtained from ginger against bacteria and fungi. It is well known that the antimicrobial activity of essential oil, extracts, and oleoresins depends primarily on their chemical composition, the solvent extraction, the methods used to obtain it, and the procedure to which the ginger has been submitted [22]. The chemical constituents of oils and their antimicrobial activity tend to be related [14]. Sesquiterpenoids and phenolic compounds (eugenol, shogaols, zingerone, gingerdiols, gingerols, etc.) are assumed to be responsible for the marked antimicrobial activity of essential oils and oleoresins. However, the overall efficiency of essential oils and oleoresins is likely to benefit from the synergistic action of all constituents [8, 9]. Generally speaking, the extract of the antimicrobial mechanism of essential oils has not been completely elucidated. However, lipophilicity or hydrophobicity of essential oils have been suggested to play an important role in antimicrobial activity, which allow them to partition between lipids of the bacterial or fungal cell membrane and mitochondria, disturbing the cell structures and interpreting them more permeable, which will lead to cell death [14]. A higher concentration of oxygenated compounds, such as geranial, 1,8-cineole, neral, borneol, alpha-terpineol, was also found in ginger's essential oil. Besides, oxygenated compounds can cause leakages of critical molecules and inhibit respiration and transport of ions. Therefore, these compounds may have many ways of influencing microbial cells, resulting in their inhibition [22].

8. Conclusion

Many chemical constituents, essential oil, and extracts of Ginger are reported for antimicrobial, anticonvulsant, analgesic, anti-inflammatory, antiulcer, gastric antisecretory, antidiabetic, nephroprotective, hepatoprotective, antitumor, anticancer, antispasmodic, antithrombotic, hypocholesterolemic, antiallergic, antiserotonergic, anticholinergic, antioxidant, larvicidal, immunomodulatory activities and other beneficial activities.

Based on our observations on ginger's antimicrobial activities, it can be said that ginger has marked antibacterial properties. It has been shown in the development of this study that ginger has many bioactive compounds that can be obtained as an essential oil, extract, and oleoresins. Some of these compounds, because of their extensive antibacterial and antifungal inhibitory range, can inhibit the most important pathogens associated with foodborne diseases. The research showed that ginger have potent antimicrobial activity and can be applied in various research areas, such as the pharmaceutical and food industries.

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Conflict of interest

There is no conflict of interest to declare.

10. References

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