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Allelopathic Plants: 26. *Alpinia zerumbet* (Pers.) B.L.Burtt & R.M.Sm. (Zingiberaceae)

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ABSTRACT

This review describes the bioactivities (antioxidant, antimicrobial, antibacterial, fungistatic, insecticidal, and herbicidal activities of the *Alpinia zerumbet* (Pers.). It is rich in total phenolics (2-20 mg gallic acid equivalent (GAE)/g) and essential oils (150 mg/g fresh weight (FW)). Principal bioactive constituents also include dihydro-5,6-dehydrokawain (DDK) (80-410 mg/g FW) and 5,6-dehydrokawain (DK) (10-100 mg/g FW), these are responsible for its allelopathic activity. The synthesis of derivatives from DDK, DK and essential oils from *A. zerumbet* might be promising to develop eco-friendly pesticides.

Keywords: Allelochemicals, allelopathic plant, allelopathy, *Alpinia zerumbet,* bioactivities, DK, DDK, essential oils, pathogen, phenolics, weeds.

1. INTRODUCTION

Alpinia zerumbet (Pers.) B.L.Burtt & R.M.Sm. (Synonym: *Alpinia cristata* Griff. or *Alpinia speciosa* (J.C.Wendl.) K.Schum., family: Zingiberaceae) called shell ginger is subtropical and tropical perennial plant, originating from West Asia (11,12). Ginger *A. zerumbet*, with its natural flavor, has been used with multipurpose, such as processing into foodstuff condiment, tea, drinks, candy, ice-cream, perfume, cosmetic, soap, and deodorant products (4,35,40). Its leaves are used to wrap rice dumplings in Taiwan or "mochi" cakes in Japan (5) and also to wrap fish prior to baking or steaming in Malaysia (4). While the fiber of creeping stems is used to produce papers or make traditional weaving handicrafts [purses, bags, cradles and pads] (5,6), the underground stems can be used to make jelly

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foods and skin cleaning products, including soap and body wash (6). Besides, due to the effective healing property, *A. zerumbet* has been popularly known as a traditional medicinal crop since ancient times and grown widely in many countries [America, Brazil, Ethiopia, Japan, China, Taiwan, Thailand, India, and Bangladesh (5,11,19,32,35,36,43)]. This plant is usually used as herbal medicine to treat stomach upset, diarrhea, fever, cold, coughing, sore throat, osteoarthritis, cardiopathy and even cancer (1,5,21,35). The possession of abundant phytochemicals (terpenoids, steroids, kava pyrones, phenolics, flavonoids and phenolic acids) increases its therapeutic value (5,7,12,34). The abundance of dihydro-5,6-dehydrokawain (DDK), 5,6-dehydrokawain (DK), essential oils, and phenols in shell ginger are antioxidant, anti-obesity, and anti-aging properties (40). Many previous studies also indicated that the pharmacological capacities attributed to extracts of *A. zerumbet* seed, leaf, stem, rhizome, pericarp and flower include anti-proliferation (34), anti-hypotensive and diuretic properties (24,35), antithrombotic and antiulcerogenic activities (29), anti-inflammatory (2,8,16,21,31), antiplatelet (20), anti-atherosclerosis (7), anti-oxidation (12,41) anti-viral, anti-bacterial and anti-fungal activities (9). Its consumption increases the longevity of Japanese in Okinawa islands, Japan (40).

The phytopharmacological profile of *Alpinia* gingers has been demonstrated in 252 publications by 2015, with 544 compounds isolated overall from 35 *Alpinia* species (25,40). In this review, the allelopathic potential of *A. zerumbet* is described as an effective biological solution for control of paddy weeds and plant pathogens to reduce dependence on synthetic herbicides and insecticides in crop production. Its phytochemicals have allelopathic properties.

2. MORPHOLOGY

The Zingiberaceae family has about 230 species (25). This plant is herbaceous, rhizomatous, aromatic, with wide, long and leathery leaves, and its stem can grow erect up to 3 m tall (5,34,40) (Figure 1). *A. zerumbet* is perennial herb with rhizomes, which are aromatic when cut, with a typical ginger smell. The leaves are two-ranked and thin, approximately 25–35 cm long. It is also used as indoor plant with smaller height, the flowers are pink and resemble seashells, hence, called shell ginger, shell flower, pink porcelain lily, variegated ginger and butterfly ginger. The fruits are ball-shaped with yellow stripes, changing to red at maturity (Figure 1). Its flower forms a funnel-shape or shell-like, with the milky white perianth and a fragrant pink apex (5,35). The fruit is a spindle-shaped capsule with longitudinal striations, including three locules that each contains > 10 seeds (46). These polyhedral seeds are covered by white membranous coats, having a typically aromatic odor and slightly pungent flavor (46).

Its all parts are edible, but data on maximum amounts tolerated by humans without toxicity are not available. *A. zerumbet* is distributed in Southernmost islands of Japan, Taiwan, Southeast and South Asia, Central America, South America, southward to Oceania and Australia, and many regions in the subtropics and tropics with many different names. It is either cultivated or grows abundantly in abandoned land. The histogram of this plant is given in Table 1.

Plants Flowers Fruits

Figure 1. Photographs of the *Alpinia zerumbet* plants grown in Okinawa

Table 1. Histogram of *Alpinia zerumbet*

Category	Description
Scientific name	*Alpinia zerumbet* (Pers.) B.L. Burtt & R.M. Sm.
Common name	Shell ginger
Taxonomic tree	Domain: Eukaryota; Kingdom: Plantae; Phylum: Spermatophyta; Subphylum: Angiospermae; Class: Monocotyledonae; Order: Zingiberaceae; Genus: *Alpinia*; Species: *Alpinia zerumbet*
Other scientific names	*Alpinia speciosa* (J.C.Wendl.) K. Schum.; *Amomum nutans* (Andrews) Schult.; *Catimbium speciosum* (J.C.Wendl.) Holttum; *Costus zerumbet* Pers.; *Languas speciosa* (J.C.Wendl.) Small; *Renealmia nutans* Andrews; *Zerumbet speciosum* J.C.Wendl.
International common names	English: Pink porcelain lily; shell flower; French: *atoumau*; Chinese: *yan shan jiang*
Other names in distributed countries	Japan: *getto*; Brazil: *colonia*; Cook Islands: *kaopui*; Cuba: *boca de lobo*; Dominican Republic: *burriquito*; Haiti: *de tui maux; tous maux*; Indonesia: *galoba merah*; Myanmar: *padegaw-gyi*; the Philippines: *langkuas na pula*; Puerto Rico: *boca de dragon*; Thailand: *khaa khom*; Tonga: *teuila*; Vietnam: *Riềng ấm*
Distribution	South, Southeast and East Asia (from India to Japan), and southward to Oceania and Australia. Cultivated as an ornamental plant in tropics and subtropics.
Uses	As spice, food, medicine, beverage, pharmacy, cosmetics, paper and ornament
References	8,12,38-42,47,49

2. ALLELOPATHY STUDIES

Allelopathy is defined as impact of one plant on its neighbor species through the chemical pathway (allelochemicals), which also indicates interactions between various objects including microbes and fungi and plants (27,33). In agriculture, allelopathic interactions between plants and other organisms can be applied to control pathogens, insects, nematodes and weeds (23) and enhancing the crop yields (49). Among mechanisms of allelochemicals actions, the induced oxidative stress has been most studied (30). Barley (*Hordeum vulgare*) extract inhibited the growth of target weeds by causing an oxidative stress, which might alter antioxidant enzymatic activities in weeds (13). Whereas, Zhao *et al*. (50) claimed that anti-aphid capacity in tobacco plants infected by *Bemisia tabaci* nymphs is related to increase in antioxidant activity of catalase. Also, Nowicka *et al*. (30) highlighted the role of prenyllipid antioxidants in *Chlamydomonas reinhardtii* responding to juglone (allelochemical from walnut trees). Therefore, the antioxidant potential is apparently associated with the allelopathic activity of plant.

2.1. Antioxidant and antimicrobial properties

The antioxidant property of *Alpinia* samples is mainly due to polyphenols (45). The highest accumulation of total phenolic contents (20.1 mg GAE/g) in the methanol extract of *A. zerumbet* leaf caused the strongest antioxidant activities (IC_{50} of DPPH assay = 0.26 mg/mL; reducing power = 8.9 mg GAE/g), as compared with different extract samples of *A. zerumbet variegate, A. purpurata, and A. galangal* (Table 2). The leaf, flower, and rhizome methanol extracts of *A. galangal* containing lower contents of total phenolics (4.7, 4.5, and 2.3 mg GAE/g, respectively) had the weakest DPPH radical scavenging and reducing power potential (Table 2) (45).

Table 2. Antioxidant property and antimicrobial activities of methanol extracts of *Alpinia* species using nutrient agar and Mueller-Hinton agar (45)

Alpinia species	Plant parts	TPC (mg GAE/g)	IC_{50} of DPPH (mg/mL)	RP (mg GAE/g)	Samples of microorganisms			
					B. cereus	*M. luteus*	*S. aureus*	*A. niger*
A. zerumbet	Leaf	20.1 ± 2.9^{a}	0.26 ± 0.04	8.9 ± 0.9^{a}	14.7(14.3)	18(16)	(11.7)	–(–)
A. zerumbet variegate	Leaf	11.5 ± 0.4^{b}	0.32 ± 0.05	6.7 ± 1.0^{b}	12(8.7)	14.6(13.7)	(8.3)	–(–)
A. purpurata	Leaf	11.9 ± 1.7^{b}	0.35 ± 0.03	7.2 ± 1.0^{b}	9(10.7)	11(10)	10(9.5)	–(–)
	Flower	13.4 ± 2.0^{b}	0.34 ± 0.06	7.4 ± 0.9^{b}	11(10.3)	13(22.2)	–(–)	–(–)
A. galangal	Leaf	3.9 ± 0.5^{c}	4.7 ± 1.5	1.7 ± 0.7^{c}	–(–)	–(–)	–(–)	–(–)
	Flower	3.0 ± 0.9^{c}	4.5 ± 1.9	1.0 ± 0.3^{c}	13(12)	14(27.4)	–(–)	–(–)
	Rhizome	2.1 ± 0.2^{d}	2.3 ± 0.2	1.1 ± 0.2^{c}	10.3(11.4)	14(15)	–(–)	11.1(26.9)

Values are reported as mean ± standard deviation (n = 3). Values followed by similar letters (a-d) in a column are not significantly different at $P < 0.05$. TPC, total phenolic content; GAE, gallic acid equivalent; DPPH, 2,2-diphenyl-1-picrylhydrazyl assay; RP, reducing power assay; "–", no inhibition zone; mean diameter of the inhibition zone is in millimeters; average standard deviation is 15%. Amount of crude extracts is 100 µg per agar disc. The values in the brackets are results shown using Mueller-Hinton agar

The results of antimicrobial activities of these *Alpinia* gingers were similar to antioxidant assays. Among methanolic leaf extracts, except *A. galangal* leaf that showed no antimicrobial activity against *Bacillus cereus, Micrococcus luteus* and *Staphylococcus aureus*, the samples from *A. zerumbet, A. zerumbet variegated* and *A. purpurata* markedly inhibited these microorganisms (Table 2). However, flower extracts of *A. galangal* and *A. purpurata* exhibited the largest inhibition zone on *Micrococcus luteus* (27.4 and 22.2, respectively), and only rhizome extract of *A. galangal* showed antifungal activity against *Aspergillus niger* (45). The difference in antimicrobial activity among *Alpinia* species may be attributed to different compositions of inhibitors in plant parts, in which flower and rhizome had stronger allelopathic activity against microbes than leaf.

Recently, fractions and extracts from *A. zerumbet* flowers have been reported to possess antibacterial activity. Costa *et al*. (10) indicated that the hexane fraction (HF) of *A. zerumbet* flowers had the broadest activity spectrum, inhibiting 10 out of 12 tested bacterial strains, especially *P. gingivalis, F. nucleatum and F. necrophorum* were suppressed at the minimum inhibitory concentration (MIC) of 64 µg/mL (Table 3) (10). The lowest MIC was observed for the ethyl acetate fraction (AF), which inhibited the growth of *S. pneumoniae* at 32 µg/mL. Besides, no extracts/fractions caused antibacterial effect against *S. agalactiae*. The presence of five secondary metabolites (steroids, triterpenoids, saponins, flavonoids and alkaloids) in each extract/fraction suggested that their content may cause the differences in activity spectrums of extracts and fractions from *A. zerumbet* flowers (10).

Table 3. Antibacterial activity of extracts and fractions obtained from flowers of *A. zerumbet* (10)

Bacterial strains	MIC values (µg/mL) of extracts and fractions						
	ME[a,b]	HF[a,c]	DF[a,d]	AF[a,e]	CM[a,f]	AE[g,h]	BF[g,i]
Porphyromonas gingivalis	256[j]	64	–[k]	–	1	–	+[l]
Prevotella intermedia	512	128	256	256	1	+	+
Peptostreptococcus anaerobius	512	128	256	256	2	–	+
Fusobacterium nucleatum	512	64	512	512	1	–	–
Fusobacterium necrophorum	–	64	–	512	1	–	–
Pseudomonas aeruginosa	–	–	–	–	256	+	+
Staphylococcus aureus	256	512	256	128	4	–	–
Streptococcus agalactiae	–	–	–	–	2	–	–
Streptococcus pyogenes	–	256	512	–	2	–	–
Streptococcus pneumonia	128	128	128	32	2	–	–
α-hemolytic Streptococcus	512	128	256	256	2	+	–
Moraxella catarrhalis	512	128	256	256	0.5	+	–

[a], agar dilution method; [b], methanol extract; [c], hexane fraction; [d], dichloromethane; [e], ethyl acetate fraction; [f], chloramphenicol (positive control); [g], overlay method; [h], alcoholic extract; [i], butanol fraction; [j], minimum inhibitory concentration (MIC); [k], no activity; [l], antibacterial activity

2.2. Plant pathogens and weeds

2.2.1. Fungistatic activity

The allelopathic properties of *Alpinia* gingers have been successfully exploited due to their strong inhibition on weeds and plant pathogens, the growth inhibitors (phenolics, flavonoids, fatty acids, alkaloids and lactones) are responsible for these activities (48). Among the allelochemicals isolated from the leaves of *A. zerumbet*, dihydro-5,6-dehydrokawain (DDK) and its synthesized derivative, dimethyl phosphorothionate at 100 µg/mL showed the strongest antifungal activities (72 % and 91 % growth inhibition of *Pythium* spp. and *Corticium rolfsii*, respectively) (Table 4) (32,40). The fungal inhibitory activity of DDK derivatives followed the order: dimethyl >

diethyl > diphenyl, suggesting that small molecular substituents had stronger activity than large ones. Besides, the extract from rhizomes of *A. galanga* (Thai ginger) with the main component 1′-acetoxychavicol acetate showed anti-phytopathogenic activity against *Alternaria porri*, *Colletotrichum gloeosporioides*, *Fusarium oxysporum* and *Phytophthora nicotianae* (28).

Table 4. Antifungal activity of dihydro-5,6-dehydrokawain and its derivatives (39)

Compounds	**Growth inhibition (%)**			
	Pythium sp.		*Corticium rolfsii*	
	100*	1000	100	1000
Dihydro-5,6-dehydrokawain	72	94	64	96
5-6-Dehydrokawain	42	86	0	54
4-Hydroxy-6-(2-phenylethyl)-2*H*-pyran-2-one	22	100	44	100
Dimethyl phosphorothionate	50	88	91	98
Diethyl phosphorothionate	18	44	57	66
Diphenyl phosphinothionate	0	3	17	29

*: a concentration in µg/mL

2.2.2. Insecticidal activity

The insecticidal activity against termites (*Coptotermes formosanus*) of DDK derivatives extracted from the leaf of *A. zerumbet* was tested at various concentrations (0.1 and 1.0 mg/filter paper) (39). The acetone solution containing 1.0 mg dimethyl and diethyl phosphorothinates showed the strongest activities of 93 % and 50 %, respectively, on the mortality of *C. formosanus* (Figure 2).

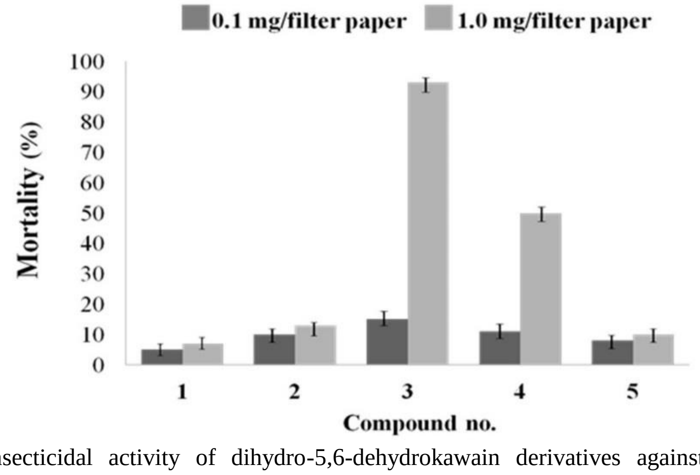

Figure 2. Insecticidal activity of dihydro-5,6-dehydrokawain derivatives against *Coptotermes formosanus* (39)
1: DDK; **2**: 4-Hydroxy-6-(2-phenylethyl)-2*H*-pyran-2-one. Phosphorous esters: **3**: Dimethyl; **4**: Diethyl; **5**: Diphenyl.

The leaf essential oils of *A. zerumbet* (OLALPZER) and *A. vittata* (OLALPVIT) and their main chemical constituents included terpinen-4-ol (19.7%) and monoterpene *β*-pinene (35.3%), respectively were reported against *Rhodnius nasutus*, a vector of Chagas disease (37). In the first 10-min treatment on *R. nasutus* fifth-instar nymphs, OLALPZER and OLALPVIT at 125 µg/mL caused 83.3% and 73.3% insect mortality, respectively. Meanwhile, terpinen-4-ol at 25 µg/mL and *β*-pinene at 44 µg/mL caused 100% mortality (Table 5).

Table 5. Mortality of *R. nasutus* fifth-instar nymphs applied with OLALPZER, OLALPVIT (125 µg/mL), and their major chemical components, terpinen-4-ol (25 µg/mL), 1,8-cineol (19 µg/mL), *β*-pinene (44 µg/mL) and *α*-pinene (12.5 µg/mL) (37)

Group	**Mortality up to 10 min (%)**	**Mortality between 10 min and 72 h (%)**
Without treatment	0	0
DMSO	0	0
OLALPZER	83.3	3.3
OLALPVIT	73.3	6.7
Terpinen-4-ol	100	0
1,8-Cineol	0	0
β-Pinene	100	0
α-Pinene	0	0

2.3. Herbicidal activity

Fujita *et al.* (15) reported that *α*-pyrones from *n*-hexane and benzene extracts of *A. zerumbet* leaves showed the inhibitory activity against lettuce (*Lactuca sativa*) seedlings. Many derivatives of DDK were synthesized and they inhibited the growth of *L. sativa* than with DDK (Table 6). The DDK at 25 µg/mL shortened the seedlings stem length of lettuce (35 %) than control, etiolated the leaf at 100 µg/mL and completely killed plant at 200 µg/mL (14). In another study, Mongkol *et al.* (28) reported the strong inhibitory role of 1′-acetoxyl group (1′-acetoxychavicol acetate) isolated from *A. galanga* on growths of lettuce and Italian ryegrass (*Lolium multiflorum*). Recently, Van *et al.* (42) demonstrated that DK and DDK isolated from the *Piper methysticum* root suppressed the growth of *Raphanus sativus* (radish). Of which, pure DK inhibited the shoot and root elongations at IC_{50} values of 265.88 and 375.33 µg/mL, respectively, while the mixture of DDK and their derivatives inhibited the root growth at IC_{50} of 15.67 µg/mL. These findings suggested that both DK and DDK from the *Alpinia* genus and *P. methysticum* could be promising source of natural growth inhibitors.

Han *et al.* (17) noted that the accumulation of water-soluble allelochemicals in the rhizome, stem and leaf aqueous extracts of Chinese ginger (*Zingiber officinale* Rosc.), a species of *Alpnia*, inhibited the seed germination and seedling growth of soybean (*Glycine max* (L.) Merr) and chive (*Allium schoenoprasum* L.). The aqueous extracts at all concentrations (10, 20, 40, and 80 g/L) reduced the germination, radical and hypocotyl length and dry weight of seedling of both tested species (soybean, chive) than control (Table 7). All samples showed dose-dependent inhibitory effects. The phytotoxic activity of different plant parts was inhibitory and followed the order stem > leaf > rhizome (17).

Table 6. Inhibitory effects of DDK and its synthesized derivatives from *A. zerumbet* leaves on seedling growth of lettuce (15)

Compounds	Growth (% of control)			
	12.5**	25	50	100
6-Styryl derivatives				
Styryl (mixture*)	–	63.7	36.7	26.7
p-Methoxystyryl (mixture)	–	54.0	46.2	41.2
o-Chlorostyryl (*cis*)	43.7	43.7	45.0	–
(*trans*)	43.7	52.5	45.0	–
m-Chlorostyryl (mixture)	–	66.2	68.7	53.7
(*cis*)	93.7	66.2	76.2	–
(*trans*)	45.0	48.7	42.5	–
p-Chlorostyryl (mixture)	–	53.7	51.2	–
(*cis*)	41.2	36.2	43.7	–
(*trans*)	43.7	41.2	55.0	–
o-Nitrostyryl (mixture)	91.2	92.5	93.7	–
m-Nitrostyryl (*cis*)	110.0	103.7	136.2	–
(*trans*)	80.0	63.7	–	–
p-Nitrostyryl (mixture)	–	61.2	77.5	–
(*cis*)	–	112.5	127.5	125.0
(*trans*)	–	132.5	131.2	122.5
6-Phenethyl derivatives				
Phenethyl (DDK)	–	63.7	55.0	22.5
p-Methoxyphenethyl	–	43.7	28.7	16.2
m-Chlorophenethyl	67.5	33.7	18.7	15.0
p- Chlorophenethyl	–	–	46.2	63.7
5,6-Dihydrophenethyl derivatives				
p-Methoxyphenethyl	–	64.2	48.7	51.2
m-Chlorophenethyl	–	–	48.7	21.5
Others				
Propenyl (*trans*)	–	115.0	116.2	–
1-Pentadienyl (mixture)	–	–	50.0	32.5
(*cis*)	86.2	78.7	68.7	–
(*trans*)	78.7	60.0	46.2	–

* : Mixture of *cis*- and *trans*-isomers at the $\Delta^{7,8}$ double bond; **: Concentration in µg/mL; – : Not tested.

Table 7. Effects of Alpinia extracts on seed germination and seedling growth of soybean and chive (17)

Ginger parts	Extract concentration (g/L)	Soybean				Chive (*Allium schoenoprasum*)			
		G (%)	HL (cm)	RL (cm)	DW (mg)	G (%)	HL (cm)	RL (cm)	DW (mg)
	0	98 ± 1.0	5.63 ± 0.3 ns	5.35 ± 0.6	23.4 ± 0.5	81 ± 3.0	5.38 ± 0.2	1.69 ± 0.2	0.79 ± 0.02
Rhizome	**10**	97 ± 1.9 ns	5.42 ± 0.3 ns	5.95 ± 4.1 ns	24.4 ± 1.2 ns	74 ± 4.0 ns	4.11 ± 0.3*	0.95 ± 0.1*	0.78 ± 0.1 ns
	20	100 ± 0.0 ns	4.99 ± 0.1 ns	4.67 ± 2.2 ns	23.7 ± 1.2 ns	77 ± 6.0 ns	3.28 ± 0.6**	0.78 ± 0.2**	0.75 ± 0.2 ns
	40	96 ± 2.2 ns	4.15 ± 0.1 ns	4.38 ± 3.7 ns	23.5 ± 1.5 ns	62 ± 5.0 ns	2.16 ± 0.3**	0.43 ± 0.0**	0.56 ± 0.1 ns
	80	91 ± 5.6 ns	3.22 ± 0.3 ns	2.55 ± 1.1**	16.3 ± 1.1**	44 ± 7.0**	0.06 ± 0.1**	0.38 ± 0.1**	0.05 ± 0.1**
Stem	**10**	96 ± 1.1 ns	4.43 ± 0.2**	3.18 ± 0.2**	20.2 ± 0.9 ns	73 ± 7.0 ns	2.93 ± 0.2**	0.62 ± 0.1**	0.63 ± 0.2 ns
	20	46 ± 8.7**	3.07 ± 0.2**	0.55 ± 0.3**	8.0 ± 3.1**	50 ± 3.0**	0.27 ± 0.1**	0.40 ± 0.1**	0.12 ± 0.1**
	40	2 ± 1.1**	0.6 ± 0.3**	0.00 ± 0.0**	3.0 ± 1.6**	36 ± 3.0**	0.00 ± 0.0**	0.29 ± 0.0**	0.00 ± 0.0**
	80	0.00 ± 0.0**	0.00 ± 0.0**	0.00 ± 0.0**	0.00 ± 0.0**	6.0 ± 4.0**	0.00 ± 0.0**	0.17 ± 0.0**	0.00 ± 0.0**
Leaf	**10**	93 ± 1.9 ns	4.93 ± 0.3 ns	6.68 ± 0.2 ns	25.2 ± 0.4 ns	73 ± 2.0 ns	3.50 ± 0.3**	0.90 ± 0.1**	0.76 ± 0.1 ns
	20	98 ± 2.2 ns	5.03 ± 0.3 ns	6.63 ± 0.6 ns	24.7 ± 2.0 ns	66 ± 2.0 ns	2.51 ± 0.2**	0.63 ± 0.2**	0.67 ± 0.2 ns
	40	83 ± 3.8*	3.55 ± 0.4*	3.25 ± 0.7 ns	19.6 ± 2.5 ns	32 ± 8.0**	0.68 ± 0.2**	0.48 ± 0.0**	0.28 ± 0.1**
	80	7 ± 5.1**	1.31 ± 0.9**	0.43 ± 0.4**	6.1 ± 6.1**	31 ± 10**	0.00 ± 0.0**	0.43 ± 0.0**	0.00 ± 0.0**

G: Germination; HL: Hypocotyl length; RL: Radicle length; DW: Dry weight; ns: Not significant; * and ** represent significant difference over control at $P < 0.05$ and $P < 0.01$, respectively.

2.4. Allelochemicals

Recently, Ma *et al.* (25) reported the chemical constituents from *Alpinia* species in last 60-years, in which, 544 compounds were reviewed with various biological activities (25). Our study mainly focussed on allelopathic and related activities of *A. zerumbet* and several *Aplinia* gingers. To date, many allelochemicals have been determined and isolated from different parts of *A. zerumbet*, which are allelopathic to the growth of test plants and organisms. The major components (camphor, sabinene, (Z)-β-ocimene, 1,8-cineole, terpinen-4-ol, α-pinene, γ-terpinene, and α-terpineol) of seed and leaf oils from *A. zerumbet* play important role in antioxidant, larvicidal and antimicrobial activities. The terpenes 1,8-cineole, camphor, borneol, methyl cinnamate, α-cadinol, T-muurolol, α-terpinenol, delta-cadinene, terpinene-4-ol, flavonoids, steroids were main chemical constituents in flower and seed essential oils, contributing to the antibacterial activity of *A. zerumbet* (10). Additionally,

Table 8. Biological activity of allelochemicals isolated from various plant parts of *Alpinia*

Plant parts	Chemicals name	Quantity	Allelopathic activities	References
Leaves	4-Hydroxy-6-(2-phenylethyl)-2*H*-pyran-2-one	-	Insecticidal, antifungal activities	39
Leaves	Dimethyl phosphorothinate	-	Insecticidal, antifungal activities	39
Leaves	Diethyl phosphorothinate	-	Insecticidal, antifungal activities	39
Leaves	Diphenyl phosphinothionate	-	Insecticidal, antifungal activities	39
Leaves	Eugenol	-	Antifungal activity	38,47
Leaves	Isothymol	-	Antifungal activity	38,47
Leaves	Thymol	-	Antifungal activity	38,47
Flowers	Alkaloids	-	Antibacterial activity	10
Flowers	Saponins	-	Antibacterial activity	10
Flowers	Triterpenoids	-	Antibacterial activity	10
Leaves, flowers	Flavonoids	-	Antibacterial activity	10,26,29
Leaves, seeds	Terpinen-4-ol	-	Insecticidal, larvicidal and antimicrobial activities	18,37
Leaves, seeds	*β*-Pinene	-	Insecticidal, larvicidal and antimicrobial activities	18,37
Leaves, stems, rhizomes, fruits	Dihydro-5,6-dehydrokawain (DDK)	80-410 (mg/g FW)	Herbicidal, insecticidal, antifungal, and antibacterial activities	15,39, 40,47,48
Leaves, stems, rhizomes, fruits	5,6-Dehydrokawain (DK)	10-100 (mg/g FW)	Herbicidal, insecticidal, antifungal, and antibacterial activities	38,39,47
Leaves, stems, rhizomes, flowers	Phenolics	2-20 mg GAE/g	Antibacterial, antimicrobial activities	3,44,45
Leaves, flowers, rhizomes, stems, seeds, pericarps	Steroids	-	Antibacterial activity	7,10
Leaves, petal, flowers, seeds, roots.	Essential oils	<150 (mg/g FW)	Insecticidal, larvicidal, and antimicrobial activities	4,14,18, 22,37,40

FW: fresh weight; GAE: gallic acid equivalent; -: not reported the appearance of isothymol, thymol, and eugenol in *A. zerumbet* essential oils showed strong antifungal activity against plant pathogenic fungi (38). Nowadays, with the development of advanced mass chromatography such as GC-MS and LC-MS, LC-ESI-MS, IR, and NMR techniques, the substances with allelopathic activity of *A. zerumbet* have been detected and identified. Principal allelochemicals identified in this plant and their relevant activities are listed in Table 8.

3. CONCLUSIONS

The phytochemicals of *A. zerumbet* include DDK and DK, phenolics, flavonoids, steroids, and alkaloids, thus this ginger possesses broad spectrum of pharmacological properties and allelopathic activities. High concentrations of essential oils, DDK and DK in different plant parts of *A. zerumbet* showed that these compounds are responsible for the allelopathic and other biological activities of this plant. Further synthesis of derivatives of these compounds might be promising to develop novel pesticides and to exploit their potential biological activities.

4. FUTURE PROSPECTS

Future research on *Alpinia zerumbet* should be done on the following aspects:

a) Clarify modes of action of DDK (dihydro-5,6-dehydrokawain), DK (5,6-dehydrokawain) and essential oils in allelopathic and other pharmaceutical activities.
b) Examine effective doses and total activity of DDK, DK, and essential oils on principal invasive and harmful weeds, fungi and plant pathogens
c) Quantify amounts of DDK, DK and essential oils in different varieties of *A. zerumbet* to develop commercial cultivars.
d) Isolate and purify further new bioactive constituents from plant parts of *A. zerumbet*.

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