Recent Advance on Bioactive Compounds from the Edible and Medicinal Fungi in China

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Abstract

Natural products and their derivatives have played a prominent role in the history of drug discovery and remain the most attractive source of potential drugs because of their structural complexity and diversity. Edible and medicinal fungi have been shown to have profound health-promoting benefits and were recognized as an important source of natural products with diverse structures and distinct pharmacological potential. There are about 10,000 fungi species and 473 medicinal fungi species in China. The fruiting bodies of these mushrooms were used in Chinese traditional medicine to treat various diseases. Recently, chemical investigation of edible and medicinal fungi collected in China led to isolation and identification of a huge number of bioactive compounds with various bioactivities including antibacterial, antioxidant, anticancer, antiplasmodial, antiproliferative, antifibrotic, and neurite outgrowth-promoting activities. In this chapter, we review the studies on isolation, structural elucidation and biologically activities of bioactive compounds derived from edible and medicinal fungi conducted by Chinese scientists after 2007. Selected compounds with unique structural features and promising bioactivities have been described herein on the basis of structural types. The main types included are terpenes, meroterpenoids, polyketides, and alkaloids. A table that lists the name of fungi species, bioactive compounds, and medicinal properties is given along with 109 references.

Keywords

Biological activities • Edible and medicinal fungi • Meroterpenoids • Natural products • Terpenoids

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Contents

Abbreviations

Bax	Bcl-2-like protein 4
Bcl-2	B-cell lymphoma 2
BrdU	5-Bromo-2-deoxyuridine
COX-2	Cyclooxygenase-2
DPP-4	Dipeptidyl peptidase-4
DPPH	2,2-Diphenyl-1-picrylhydrazyl
GPP	Geranyl pyrophosphate
HMGR	3-Hydroxy-3-methylglutaryl-CoA reductase
IC_{50}	Half maximal inhibitory concentration
iNOS	Inducible nitric oxide synthase
LPS	Lipopolysaccharide
MCP-1	Monocyte chemotactic protein 1
MTT	3-(4,5-Dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide
PTP1B	Protein tyrosine phosphatase 1B
ROS	Reactive oxygen species
TCM	Traditional Chinese medicine
TGF-β1	Transforming growth factor β1

9.1 Introduction

Edible and medicinal fungi have been widely consumed as food ingredients for centuries, not only for their good flavor and texture but also for their substantial nutritional value and potential medicinal value (Zjawiony 2004). It is commonly accepted that there are about 10,000 fungi species and 473 medicinal fungi species in China (Dai and Yang 2008). The fruiting bodies of these mushrooms were used in Chinese traditional medicine to treat various diseases, such as the fruiting bodies of *Hericium erinaceus* was used to treat gastricism and hyperglycemia (Mizuno 1999); *Antrodia camphorata* for treating liver diseases, food and drug intoxication, diarrhea, abdominal pain, hypertension, allergies, skin itching, and tumorigenic diseases (Ao et al. 2009); *Ganoderma lucidum* and *Ganoderma sinense* for the treatment of neurasthenia, insomnia, anorexia, dizziness, chronic hepatitis, hypercholesterolemia, coronary heart disease, hypertension, and carcinomas (China Pharmacopoeia Committee 2010); and so on. Recently, edible and medicinal fungi were recognized as a prolific source of natural products with diverse structures and distinct pharmacological potential, such as davallialactone from *Inonotus xaranticus* improving the aging process (Yang et al. 2013a); thelephantin O from *Thelephora aurantiotincta* inhibiting the proliferation of cancer cells (Norikura et al. 2013); 4,7-dimethoxy-5-methyl-1,3-benzodioxole (DMB) from *A. camphorata* exhibiting antiproliferative, antitumor, and anti-inflammatory effects (Chen et al. 2007; Tu et al. 2012); erinacines A-K from *H. erinaceus* possessing stimulatory activity for the biosynthesis of nerve growth factor (Kawagishi et al. 1994, 1996a, b, 2006; Lee et al. 2000); and so on. Herein, we review the studies on isolation, structural elucidation, and biological activities of the bioactive compounds derived from edible and medicinal fungi conducted by Chinese scientists after 2007. The names, fungi sources, and bioactivities, along with the references of these bioactive compounds, have been listed in Table 9.1.

9.2 Terpenoids

Terpenoids are the most abundant and structurally diverse higher fungi natural products. Sesquiterpenoids gained attention because of their roles for finding new lead structures for medicinal chemistry. More than 30 skeletons of sesquiterpenoids have been reported in edible and medicinal fungi, including humulane, illudane, tremulane, lactarane, marasmane, and drimane. Diterpenoids have fewer structures than sesquiterpenoids. In this review, we mainly concentrate on cyathane. As for triterpenoids, lanostane is the most classic type.

9.2.1 Monoterpenoids

Five monoterpenoids (**1**–**5**) were obtained from the solid culture of *Pleurotus cornucopiae*. Compounds **1**–**5** showed moderate inhibition against nitric oxide

Table 9.1 Bioactive compounds isolated from edible and medical fungi in China

Fungi species	Compounds	Bioactivities	References
Pleurotus cornucopiae	**1**	Inhibition of nitric oxide production	Wang et al. (2013a)
	2	Inhibition of nitric oxide production	Wang et al. (2013a)
	3	Inhibition of nitric oxide production	Wang et al. (2013a)
	4	Inhibition of nitric oxide production	Wang et al. (2013a)
	5	Inhibition of nitric oxide production	Wang et al. (2013a)
	Pleurospiroketal A (**61**)	Inhibition of nitric oxide production	Wang et al. (2013b)
	Pleurospiroketal B (**62**)	Inhibition of nitric oxide production	Wang et al. (2013b)
	Pleurospiroketal C (**63**)	Inhibition of nitric oxide production	Wang et al. (2013b)
	Pleurospiroketal D (**64**)	–	Wang et al. (2013b)
	Pleurospiroketal E (**65**)	–	Wang et al. (2013b)
	66	Cytotoxicity	Wang et al. (2013b)
	67	Cytotoxicity	Wang et al. (2013b)
	68	Cytotoxicity	Wang et al. (2013b)
Flammulina velutipes	5-(Hydroxymethyl)-2-(prop-1-en-2-yl) cyclohexanol (**6**) 1-en-2-yl) cyclohexanol (**6**)	–	Cai et al. (2013)
	Flamvelutpenoid A (**7**)	Antibacterial activity	Wang et al. (2012a)
	Flamvelutpenoid B (**8**)	Antibacterial activity	Wang et al. (2012a)
	Flamvelutpenoid C (**9**)	Antibacterial activity	Wang et al. (2012a)
	Flamvelutpenoid D (**10**)	Antibacterial activity	Wang et al. (2012a)
	Flamvelutpenoid E (**11**)	–	Tao et al. (2016a)
	Flamvelutpenoid F (**12**)	–	Tao et al. (2016a)
	Enokipodin E (**13**)	–	Wang et al. (2012b)
	Enokipodin F (**14**)	Antifungal activity	Wang et al. (2012b)
	Enokipodin G (**15**)	Antifungal activity	Wang et al. (2012b)
	Enokipodin H (**16**)	–	Wang et al. (2012b)
	Enokipodin I (**17**)	Antifungal activity	Wang et al. (2012b)
	Enokipodin J (**18**)	Cytotoxicity; antioxidant activity	Wang et al. (2012b)

	2,5-Cuparadiene-1,4-dione (**19**)	Cytotoxicity; antioxidant activity	Wang et al. (2012b)
	Enokipodin B (**20**)	Cytotoxicity; antioxidant activity	Wang et al. (2012b)
	Enokipodin D (**21**)	Cytotoxicity; antioxidant activity	Wang et al. (2012b)
	Flammufuranone A (**22**)	–	Tao et al. (2016a)
	Flammufuranone B (**23**)	–	Tao et al. (2016a)
	Sterpurol A (**24**)	–	Wang et al. (2012b)
	Sterpurol B (**25**)	–	Wang et al. (2012b)
	Sterpuric acid (**26**)	–	Wang et al. (2012b)
	Flammulinol A (**27**)	–	Wang et al. (2012c)
	Flammulinolide A (**28**)	Cytotoxicity	Wang et al. (2012c)
	Flammulinolide B (**29**)	Cytotoxicity	Wang et al. (2012c)
	Flammulinolide C (**30**)	Cytotoxicity	Wang et al. (2012c)
	Flammulinolide D (**31**)	–	Wang et al. (2012c)
	Flammulinolide E (**32**)	–	Wang et al. (2012c)
	Flammulinolide F (**33**)	Cytotoxicity	Wang et al. (2012c)
	Flammulinolide G (**34**)	–	Wang et al. (2012c)
	Flammuspirone A (**35**)	HMG-CoA reductase inhibitor	Tao et al. (2016a)
	Flammuspirone B (**36**)	–	Tao et al. (2016a)
	Flammuspirone C (**37**)	HMG-CoA reductase inhibitor; DPP-4 inhibitory activity	Tao et al. (2016a)
	Flammuspirone D (**38**)	DPP-4 inhibitory activity	Tao et al. (2016a)
	Flammuspirone E (**39**)	DPP-4 inhibitory activity	Tao et al. (2016a)
	Flammuspirone F (**40**)	–	Tao et al. (2016a)
	Flammuspirone G (**41**)	–	Tao et al. (2016a)
	Flammuspirone H (**42**)	DPP-4 inhibitory activity	Tao et al. (2016a)
	Flammuspirone I (**43**)	–	Tao et al. (2016a)
	Flammuspirone J (**44**)	DPP-4 inhibitory activity	Tao et al. (2016a)
	7,13,14-Trihydroxy-4-cadinen-15-oic acid methyl ester (**45**)	HMG-CoA reductase inhibitor	Tao et al. (2016a)
		DPP-4 inhibitory activity	

(continued)

Table 9.1 (continued)

Fungi species	Compounds	Bioactivities	References
	1,2,6,10-Tetrahydroxy-3,9-epoxy-14-nor-5(15)-eudesmane (**46**)	HMG-CoA reductase inhibitor	Tao et al. (2016a)
		DPP-4 inhibitory activity	
Pleurotus cystidiosus	Pleuroton A (**47**)	Cytotoxicity	Zheng et al. (2015)
	Pleuroton B (**48**)	Cytotoxicity	Zheng et al. (2015)
	Clitocybulol D (**49**)	Cytotoxicity	Zheng et al. (2015)
	Clitocybulol E (**50**)	Cytotoxicity	Zheng et al. (2015)
	Clitocybulol F (**51**)	Cytotoxicity	Zheng et al. (2015)
	Clitocybulol G (**52**)	PTP1B inhibitory activity	Tao et al. (2016b)
	Clitocybulol H (**53**)	–	Tao et al. (2016b)
	Clitocybulol I (**54**)	–	Tao et al. (2016b)
	Clitocybulol J (**55**)	–	Tao et al. (2016b)
	Clitocybulol K (**56**)	–	Tao et al. (2016b)
	Clitocybulol L (**57**)	PTP1B inhibitory activity	Tao et al. (2016b)
	Clitocybulol M (**58**)	–	Tao et al. (2016b)
	Clitocybulol N (**59**)	–	Tao et al. (2016b)
	Clitocybulol O (**60**)	–	Tao et al. (2016b)
Pleurotus citrinopileatus	Pleurospiroketal F (**69**)	–	Tao et al. (2016c)
	Pleurotin A (**70**)	PTP1B inhibitory activity	Tao et al. (2016c)
	Pleurotin B (**71**)	–	Tao et al. (2016c)
	Pleurotin C (**72**)	–	Tao et al. (2016c)
	Pleurotin D (**73**)	–	Tao et al. (2016c)
	Pleurotin E (**74**)	PTP1B inhibitory activity	Tao et al. (2016c)
	Pleurotin F (**75**)	–	Tao et al. (2016c)
	5,7-Dimethoxyisobenzofuran-1(3H)-one (**396**)	Iron-chelating capacity	Li et al. (2013c)
		Antioxidant activity	
	3,5-Dihydroxybenzyl acetate (**397**)	Iron-chelating capacity	Li et al. (2013c)
	2,4-Dihydroxy-6-(hydroxymethyl) benzaldehyde (**398**)	Iron-chelating capacity	Li et al. (2013c)

Laetiporus sulphureus	Sulphureuine B (**76**)	Induces apoptosis	He et al. (2015a)
	Sulphureuine C (**77**)	–	He et al. (2015a)
	Sulphureuine D (**78**)	–	He et al. (2015a)
	Sulphureuine E (**79**)	–	He et al. (2015a)
	Sulphureuine F (**80**)	–	He et al. (2015a)
	Sulphureuine G (**81**)	–	He et al. (2015a)
	Sulphureuine H (**82**)	–	He et al. (2015a)
	Phellinuin J (**83**)	–	He et al. (2015b)
	Sulphureuine A (**84**)	–	He et al. (2015b)
	15α-Hydroxy-3,4-secolanosta-4(28),8,24-triene-3,21-dioic acid (**226**)	–	Yin et al. (2015)
	5α-Hydroxy-3,4-seco-lanosta-4(28),8,24-triene-3,21-dioic acid 3-methyl ester (**227**)	–	Yin et al. (2015)
	15α-Acetoxylhydroxytrametenolic acid (**228**)	–	Yin et al. (2015)
	Versisponic acid D (**229**)	–	Yin et al. (2015)
	230	Cytotoxicity	He et al. (2015a)
	231	–	He et al. (2015a)
	Eburicoic acid (**232**)	Attenuated H+/K+-ATPase activity	Wang et al. (2015b)
Xylaria nigripes	Nigriterpene A (**85**)	–	Chang et al. (2017)
	Nigriterpene B (**86**)	–	Chang et al. (2017)
	Nigriterpene C (**87**)	Anti-inflammatory effect	Chang et al. (2017)
	Nigriterpene D (**88**)	–	Chang et al. (2017)
	Nigriterpene E (**89**)	–	Chang et al. (2017)
	Nigriterpene F (**90**)	–	Chang et al. (2017)

(continued)

Table 9.1 (continued)

Fungi species	Compounds	Bioactivities	References
Boletus edulis	Boledulin A (**91**)	Cytotoxicity	Feng et al. (2011)
	Boledulin B (**92**)	–	Feng et al. (2011)
	Boledulin C (**93**)	–	Feng et al. (2011)
Inonotus vaninii	Inonolane A (**94**)	–	Yang et al. (2013b)
Dictyophora indusiata	Albaflavenone (**96**)	Camphor-like odor	Huang et al. (2011)
Cyathus africanus	Cyathin D (**97**)	–	Han et al. (2013)
	Cyathin E (**98**)	–	Han et al. (2013)
	Cyathin F (**99**)	Inhibition of nitric oxide production	Han et al. (2013)
	Cyathin G (**100**)	–	Han et al. (2013)
	Cyathin H (**101**)	Inhibition of nitric oxide production	Han et al. (2013)
	Neosarcodonin O (**102**)	Inhibition of nitric oxide production; cytotoxicity	Han et al. (2013)
	Cyathatriol (**103**)	–	Han et al. (2013)
	11-O-acetylcyathatriol (**104**)	Inhibition of nitric oxide production; cytotoxicity	Han et al. (2013)
	Cyathin R (**105**)	Inducing apoptosis	Huang et al. (2015)
	Cyathin T (**106**)	Inhibition of nitric oxide production	Han et al. (2015)
	Cyathin V (**107**)	–	Han et al. (2015)
	Cyathin W (**108**)	Inhibition of nitric oxide production; cytotoxicity	Han et al. (2015)
	Cyathin Q (**109**)	Inducing apoptosis	He et al. (2016)
Cyathus hookeri	Cyathin I (**110**)	Inhibition of nitric oxide production	Xu et al. (2013)
	(12R)-11a,14a-epoxy-13a,14b,15-trihydroxycyath-3-ene (**111**)	Inhibition of nitric oxide production	Xu et al. (2013)
	Erinacine I (**112**)	Inhibition of nitric oxide production	Xu et al. (2013)

Cyathus gansuensis	Cyathin J (**113**)	Inhibition of nitric oxide production	Wang et al. (2014a)
	Cyathin K (**114**)	Inhibition of nitric oxide production	Wang et al. (2014a)
	Cyathin L (**115**)	–	Wang et al. (2014a)
	Cyathin M (**116**)	Inhibition of nitric oxide production	Wang et al. (2014a)
	Cyathin N (**117**)	–	Wang et al. (2014a)
	Cyathin O (**118**)	–	Wang et al. (2014a)
	Cyathin P (**119**)	–	Wang et al. (2014a)
	120	Inhibition of nitric oxide production	Wang et al. (2014a)
	121	–	Wang et al. (2014a)
Cyathus striatus	Striatoid A (**122**)	Enhanced nerve growth factor (NGF)-mediated neurite outgrowth	Bai et al. (2015)
	Striatoid B (**123**)	Enhanced nerve growth factor (NGF)-mediated neurite outgrowth	Bai et al. (2015)
	Striatoid C (**124**)	Enhanced nerve growth factor (NGF)-mediated neurite outgrowth	Bai et al. (2015)
	Striatoid D (**125**)	Enhanced nerve growth factor (NGF)-mediated neurite outgrowth	Bai et al. (2015)
	Striatoid E (**126**)	Enhanced nerve growth factor (NGF)-mediated neurite outgrowth	Bai et al. (2015)
	Striatoid F (**127**)	Enhanced nerve growth factor (NGF)-mediated neurite outgrowth	Bai et al. (2015)
Hericium erinaceus	**128**	Cytotoxicity	Zhang et al. (2015a)
	Erinacerin C (**351**)	–	Wang et al. (2015c)
	Erinacerin D (**352**)	α-Glucosidase inhibitory activity	Wang et al. (2015c)
	Erinacerin E (**353**)	α-Glucosidase inhibitory activity	Wang et al. (2015c)
	Erinacerin F (**354**)	α-Glucosidase inhibitory activity	Wang et al. (2015c)
	Erinacerin G (**355**)	α-Glucosidase inhibitory activity	Wang et al. (2015c)

(continued)

Table 9.1 (continued)

Fungi species	Compounds	Bioactivities	References
	Erinacerin H (**356**)	α-Glucosidase inhibitory activity	Wang et al. (2015c)
	Erinacerin I (**357**)	α-Glucosidase inhibitory activity	Wang et al. (2015c)
	Erinacerin J (**358**)	α-Glucosidase inhibitory activity	Wang et al. (2015c)
	Erinacerin K (**359**)	α-Glucosidase inhibitory activity	Wang et al. (2015c)
	Erinacerin L (**360**)	α-Glucosidase inhibitory activity	Wang et al. (2015c)
	Erinacerin Q (**361**)	α-Glucosidase inhibitory activity	Wang et al. (2015d)
		PTP1B inhibitory activity	
	Erinacerin R (**362**)	α-Glucosidase inhibitory activity	Wang et al. (2015d)
		PTP1B inhibitory activity	
	Erinacerin S (**363**)	α-glucosidase inhibitory activity	Wang et al. (2015d)
		PTP1B inhibitory activity	
	Erinacerin T (**364**)	α-Glucosidase inhibitory activity	Wang et al. (2015d)
		PTP1B inhibitory activity	
	Erinaceolactam A (**365**)	–	Wang et al. (2015c)
	Erinaceolactam B (**366**)	–	Wang et al. (2015c)
	Erinaceolactam C (**367**)	–	Wang et al. (2015c)
	Erinaceolactam D (**368**)	–	Wang et al. (2015c)
	Erinaceolactam E (**369**)	–	Wang et al. (2015c)
	Erinaceolactone D (**370**)	–	Wang et al. (2016d)
	Erinaceolactone E (**371**)	–	Wang et al. (2016d)
	Erinaceolactone F (**372**)	–	Wang et al. (2016d)
	Hericenone K (**373**)	Stimulate NGF-mediated neurite outgrowth	Zhang et al. (2015b)
	Hericenone L (**374**)	Cytotoxicity	Ma et al. (2012)
	Erinacerin M (**399**)	Cytotoxicity	Wang et al. (2015d)
	Erinacerin N (**400**)	Cytotoxicity	Wang et al. (2015d)

	Erinacerin O (**401**)	Cytotoxicity	Wang et al. (2015d)
	Erinacerin P (**402**)	Cytotoxicity	Wang et al. (2015d)
Antrodia camphorata	Antrocamol LT1 (**375**)	Cytotoxicity	Yen et al. (2015)
	Antrocamol LT2 (**376**)	Cytotoxicity	Yen et al. (2015)
	Antrocamol LT3 (**377**)	Cytotoxicity	Yen et al. (2015)
	Antroquinonol (**378**)	Cytotoxicity	Yen et al. (2015)
	Antroquinonol B (**379**)	NO inhibition	Yang et al. (2009)
	4-Acetyl-antroquinonol B (**380**)	NO inhibition	Yang et al. (2009)
	Antroquinonol D (**381**)	Inhibiting breast cancer growth and migration potential	Wang et al. (2014b)
Pleurotus eryngii	Eryngiolide A (**129**)	Cytotoxicity	Wang et al. (2012d)
	2,3,6,23-Tetrahydroxy-urs-12-en-28-oic acid (**233**)	Antiproliferative activity	Xue et al. (2015)
	2,3,23-Trihydroxyurs-12-en-28-oic acid (**234**)	Antiproliferative activity	Xue et al. (2015)
	Lupeol (**235**)	Antiproliferative activity	Xue et al. (2015)
	6-Dimethoxyisobenzofuran-1(3H)-one (**395**)	–	Liu et al. (2013)
Ganoderma boninense	Ganoboninketal A (**130**)	Antimalarial effect	Ma et al. (2014)
	Ganoboninketal B (**131**)	Antimalarial effect	Ma et al. (2014)
	Ganoboninketal C (**132**)	Antimalarial effect	Ma et al. (2014)
	Ganoboninone A (**133**)	Antimalarial effect	Ma et al. (2015)
	Ganoboninone B (**134**)	Antimalarial effect	Ma et al. (2015)
	Ganoboninone C (**135**)	Antimalarial effect	Ma et al. (2015)
	Ganoboninone D (**136**)	Antimalarial effect	Ma et al. (2015)
	Ganoboninone E (**137**)	Antimalarial effect	Ma et al. (2015)
	Ganoboninone F (**138**)	Antimalarial effect	Ma et al. (2015)

(continued)

Table 9.1 (continued)

Fungi species	Compounds	Bioactivities	References
Ganoderma leucocontextum	Ganoleucoin A (**139**)	HMG-CoA reductase inhibitor/cytotoxicity	Wang et al. (2015a)
	Ganoleucoin B (**140**)	Cytotoxicity	Wang et al. (2015a)
	Ganoleucoin C (**141**)	HMG-CoA reductase inhibitor	Wang et al. (2015a)
	Ganoleucoin D (**142**)	–	Wang et al. (2015a)
	Ganoleucoin E (**143**)	–	Wang et al. (2015a)
	Ganoleucoin F (**144**)	HMG-CoA reductase inhibitor	Wang et al. (2015a)
		Cytotoxicity	
	Ganoleucoin G (**145**)	Cytotoxicity	Wang et al. (2015a)
	Ganoleucoin H (**146**)	–	Wang et al. (2015a)
	Ganoleucoin I (**147**)	–	Wang et al. (2015a)
	Ganoleucoin J (**148**)	HMG-CoA reductase inhibitor	Wang et al. (2015a)
		Cytotoxicity	
	Ganoleucoin K (**149**)	HMG-CoA reductase inhibitor	Wang et al. (2015a)
	Ganoleucoin L (**150**)	HMG-CoA reductase inhibitor	Wang et al. (2015a)
		Cytotoxicity	
	Ganoleucoin M (**151**)	HMG-CoA reductase inhibitor	Wang et al. (2015a)
	Ganoleucoin N (**152**)	HMG-CoA reductase inhibitors	Wang et al. (2015a)
	Ganoleucoin O (**153**)	–	Wang et al. (2015a)
	Ganoleucoin P (**154**)	Cytotoxicity	Wang et al. (2015a)
	Leucocontextin A (**155**)	–	Zhao et al. (2016a)
	Leucocontextin B (**156**)	–	Zhao et al. (2016a)
	Leucocontextin C (**157**)	–	Zhao et al. (2016a)
	Leucocontextin D (**158**)	–	Zhao et al. (2016a)

	Leucocontextin E (**159**)	–	Zhao et al. (2016a)
	Leucocontextin F (**160**)	–	Zhao et al. (2016a)
	Leucocontextin G (**161**)	–	Zhao et al. (2016a)
	Leucocontextin H (**162**)	–	Zhao et al. (2016a)
	Leucocontextin I (**163**)	–	Zhao et al. (2016a)
	Leucocontextin J (**164**)	–	Zhao et al. (2016a)
	Leucocontextin K (**165**)	–	Zhao et al. (2016a)
	Leucocontextin L (**166**)	–	Zhao et al. (2016a)
	Leucocontextin M (**167**)	–	Zhao et al. (2016a)
	Leucocontextin N (**168**)	–	Zhao et al. (2016a)
	Leucocontextin O (**169**)	–	Zhao et al. (2016a)
	Leucocontextin P (**170**)	–	Zhao et al. (2016a)
	Leucocontextin Q (**171**)	–	Zhao et al. (2016a)
	Leucocontextin R (**172**)	Cytotoxicity	Zhao et al. (2016a)
	Leucocontextin S (**173**)	–	Zhao et al. (2016b)
	Leucocontextin T (**174**)	–	Zhao et al. (2016b)
	Leucocontextin U (**175**)	–	Zhao et al. (2016b)
	Leucocontextin V (**176**)	–	Zhao et al. (2016b)
	Leucocontextin W (**177**)	–	Zhao et al. (2016b)
	Leucocontextin X (**178**)	–	Zhao et al. (2016b)
	Ganoleucin A (**342**)	α-Glucosidase inhibitory activity	Wang et al. (2016b)
	Ganoleucin B (**343**)	–	Wang et al. (2016b)
	Ganoleucin C (**344**)	α-Glucosidase inhibitory activity	Wang et al. (2016b)
	Ganodilactone (**345**)	Pancreatic lipase inhibitory activities	Chen et al. (2016)

(continued)

Table 9.1 (continued)

Fungi species	Compounds	Bioactivities	References
Ganoderma lucidum	Ganoderitriol M (**179**)	–	Chen et al. (2009)
	Ethyl lucidenate A (**180**)	Cytotoxicity	Li et al. (2013a)
	Ethyl 7β-hydroxy-4,4,14α-trimethyl-3,11,15-trioxo-5α-chol-8-en-24-oate (**181**)	NGF-like neuronal survival-promoting activities	Zhang et al. (2011)
	23S-hydroxy-3,7,11,15-tetraoxo-lanost-8,24E-diene-26-oic acid (**182**)	Cytotoxicity	Guan et al. (2008)
	12β-Acetoxy-3β-hydroxy-7,11,15,23-tetraoxo-lanost-8,20E-diene-26-oic acid (**183**)	Cytotoxicity	Guan et al. (2008)
	184	–	Cheng et al. (2010)
	185	Cytotoxicity	Cheng et al. (2010)
	186	–	Cheng et al. (2010)
	187	Cytotoxicity	Cheng et al. (2010)
	188	Cytotoxicity	Cheng et al. (2010)
	189	–	Cheng et al. (2010)
	(+)-Lingzhiol (**236**)	Inhibit the phosphorylation of Smad3	Yan et al. (2013)
	(−)-Lingzhiol (**237**)	Inhibit the phosphorylation of Smad3	Yan et al. (2013)
	Chizhine A (**238**)	Inhibit MCP-1 and fibronectin production	Luo et al. (2015a)
	Chizhine B (**239**)	Inhibit MCP-1 and fibronectin production	Luo et al. (2015a)
	Chizhine C (**240**)	Inhibit MCP-1 and fibronectin production	Luo et al. (2015a)
	Chizhine D (**241**)	Inhibit MCP-1 and fibronectin production	Luo et al. (2015a)
	Chizhine E (**242**)	Inhibit MCP-1 and fibronectin production	Luo et al. (2015a)
	Chizhine F (**243**)	Inhibit MCP-1 and fibronectin production	Luo et al. (2015a)
	Lingzhifuran A (**244**)	Inhibit TGF-β1-induced Smad3 phosphorylation	Ding et al. (2016)
	Lingzhilactone D (**245**)	Inhibit TGF-β1-induced Smad3 phosphorylation	Ding et al. (2016)
	Lingzhilactone E (**246**)	–	Ding et al. (2016)
	Lingzhilactone F (**247**)	–	Ding et al. (2016)

	Lucidimine A (**412**)	–	Zhao et al. (2015)
	Lucidimine B (**413**)	–	Zhao et al. (2015)
	Lucidimine C (**414**)	–	Zhao et al. (2015)
	Lucidimine D (**415**)	–	Zhao et al. (2015)
Ganoderma sinense	Ganosinensine (**95**)	–	Liu et al. (2012)
	Ganolactone B (**190**)	–	Qiao et al. (2007)
	Ganoderiol A triacetate (**191**)	–	Qiao et al. (2007)
	Methyl ganosinensate A (**192**)	–	Wang et al. (2010)
	Ganosinensic acid A (**193**)	–	Wang et al. (2010)
	Ganosinensic acid B (**194**)	–	Wang et al. (2010)
	Ganosineniol A (**195**)	–	Liu et al. (2012)
	Ganosinoside A (**196**)	–	Liu et al. (2012)
	Ganoderic acid Jc (**197**)	Cytotoxicity	Liu et al. (2012)
	Ganoderic acid Jd (**198**)	–	Liu et al. (2012)
	Ganodermatetraol (**199**)	Induction ability of hPXR-mediated CYP3A4 expression	Liu et al. (2012)
	Ganolucidic acid γa (**200**)	–	Liu et al. (2012)
	Ganolucidate F (**201**)	Induction ability of hPXR-mediated CYP3A4 expression	Liu et al. (2012)
	Ganoderiol J (**202**)	–	Liu et al. (2012)
	Methyl lucidenate Ha (**203**)	–	Liu et al. (2012)
	(−)-Sinensilactam A (**261**)	Smad3 phosphorylation inhibitor	Luo et al. (2015b)
	(+)-Sinensilactam A (**262**)	Smad3 phosphorylation inhibitor	Luo et al. (2015b)
	Zizhine A (**263**)	–	Cao et al. (2016)
	Zizhine B (**264**)	–	Cao et al. (2016)
	Zizhine C (**265**)	–	Cao et al. (2016)
	Zizhine D (**266**)	–	Cao et al. (2016)

(continued)

Table 9.1 (continued)

Fungi species	Compounds	Bioactivities	References
	Zizhine E (**267**)	–	Cao et al. (2016)
	Zizhine F (**268**)	–	Cao et al. (2016)
	Sinensine A (**407**)	Protecting the injury induced by hydrogen peroxide oxidation on HUVEC	Liu et al. (2010)
	Sinensine B (**408**)	–	Liu et al. (2011)
	Sinensine C (**409**)	–	Liu et al. (2011)
	Sinensine D (**410**)	–	Liu et al. (2011)
	Sinensine E (**411**)	–	Liu et al. (2011)
Ganoderma cochlear	Fornicatin G (**204**)	–	Peng et al. (2012)
	Fornicatin H (**205**)	–	Peng et al. (2012)
	Cochlate A (**206**)	–	Peng et al. (2014a)
	Cochlate B (**207**)	–	Peng et al. (2014a)
	Fornicatin D (**208**)	Hepatoprotective activity	Peng et al. (2014a)
	Fornicatin E (**209**)	–	Peng et al. (2014a)
	Fornicatin F (**210**)	Hepatoprotective activity	Peng et al. (2014a)
	Ganodercochlearin A (**211**)	–	Peng et al. (2014a)
	Ganodercochlearin A (**212**)	–	Peng et al. (2014a)
	Ganodercochlearin A (**213**)	–	Peng et al. (2014a)
	Ganocochlearic acid A (**214**)	–	Peng et al. (2015a)
	Cochlate C (**215**)	–	Peng et al. (2015a)
	Cochlearic acid A (**216**)	–	Peng et al. (2015a)
	Ganodecochlearin D (**217**)	Cytotoxicity	Peng et al. (2015a)
	Ganodercochlearin E (**218**)	–	Peng et al. (2015a)
	Cochlearic acid B (**219**)	–	Peng et al. (2015a)
	Ganodercochlearin F (**220**)	Cytotoxicity	Peng et al. (2015a)
	Ganodercochlearin G (**221**)	Cytotoxicity	Peng et al. (2015a)

	Ganodercochlearin H (**222**)	Cytotoxicity	Peng et al. (2015a)
	Ganodercochlearin I (**223**)	–	Peng et al. (2015a)
	Ganodercochlearin J (**224**)	Cytotoxicity	Peng et al. (2015a)
	Ganodercochlearin K (**240**)	Cytotoxicity	Peng et al. (2015a)
	Ganocin A (**269**)	–	Peng et al. (2014b)
	Ganocin B (**270**)	–	Peng et al. (2014b)
	Ganocin C (**271**)	–	Peng et al. (2014b)
	Ganocin D (**272**)	Anti-AChE activity	Peng et al. (2014b)
	Cochlearol A (**273**)	–	Dou et al. (2014)
	Cochlearol A (**274**)	Inhibitor of p-Smads	Dou et al. (2014)
	Cochlearoid A (**275**)	Inhibited Cav3.1 TTCC	Zhou et al. (2015)
	Cochlearoid B (**276**)	–	Zhou et al. (2015)
	Cochlearoid C (**277**)	–	Zhou et al. (2015)
	Cochlearoid D (**278**)	Inhibited Cav3.1 TTCC	Zhou et al. (2015)
	Cochlearoid E (**279**)	–	Zhou et al. (2015)
	Cochlearine A (**280**)	Inhibited Cav3.1 TTCC	Zhou et al. (2015)
	Cochlearine B (**281**)	–	Zhou et al. (2015)
	Ganoderin A (**282**)	Antioxidant effect	Peng et al. (2015b)
	Ganocochlearin A (**283**)	Antioxidant effect	Peng et al. (2015b)
	Ganocochlearin B (**284**)	Antioxidant effect	Peng et al. (2015b)
	Ganocochlearin C (**285**)	Antioxidant effect	Peng et al. (2015b)
	Ganocochlearin D (**286**)	Antioxidant effect	Peng et al. (2015b)
	Fornicin D (**287**)	Antioxidant effect	Peng et al. (2015b)

(continued)

Table 9.1 (continued)

Fungi species	Compounds	Bioactivities	References
	Ganomycin C (**288**)	Antioxidant effect	Peng et al. (2015b)
	Cochlearoid F (**289**)	Inhibitory activity on fibronectin	Wang et al. (2016a)
	Cochlearoid G (**290**)	Inhibitory activity on fibronectin	Wang et al. (2016a)
	Cochlearoid H (**291**)	Inhibitory activity on fibronectin	Wang et al. (2016a)
	Cochlearoid I (**292**)	Inhibitory activity on fibronectin	Wang et al. (2016a)
	Cochlearoid J (**293**)	–	Wang et al. (2016a)
	Cochlearoid K (**294**)	Inhibitory activity on fibronectin	Wang et al. (2016a)
Ganoderma applanatum	Applanatumin A (**295**)	Antifibrotic activity	Luo et al. (2015c)
	Applanatumol A (**296**)	ECM inhibitors	Luo et al. (2016a)
	Applanatumol B (**297**)	ECM inhibitors	Luo et al. (2016a)
	(±)-Ganoapplanin (**298**)	–	Li et al. (2016a)
	Spiroapplanatumine A (**299**)	–	Luo et al. (2017)
	Spiroapplanatumine B (**300**)	–	Luo et al. (2017)
	Spiroapplanatumine C (**301**)	–	Luo et al. (2017)
	Spiroapplanatumine D (**302**)	–	Luo et al. (2017)
	Spiroapplanatumine E (**303**)	–	Luo et al. (2017)
	Spiroapplanatumine F (**304**)	–	Luo et al. (2017)
	Spiroapplanatumine G (**305**)	Inhibited JAK3 kinase	Luo et al. (2017)
	Spiroapplanatumine H (**306**)	Inhibited JAK3 kinase	Luo et al. (2017)
	Spiroapplanatumine I (**307**)	–	Luo et al. (2017)
	Spiroapplanatumine J (**308**)	–	Luo et al. (2017)
	Spiroapplanatumine K (**309**)	–	Luo et al. (2017)
	Spiroapplanatumine L (**310**)	–	Luo et al. (2017)
	Spiroapplanatumine M (**311**)	–	Luo et al. (2017)

	Spiroapplanatumine N (**312**)	–	Luo et al. (2017)
	Spiroapplanatumine O (**313**)	–	Luo et al. (2017)
	Spiroapplanatumine P (**314**)	–	Luo et al. (2017)
	Spiroapplanatumine Q (**315**)	–	Luo et al. (2017)
	Applanatumol C (**316**)	COX-2 inhibitory effect	Luo et al. (2016b)
	Applanatumol D (**317**)	–	Luo et al. (2016b)
	Applanatumol E (**318**)	–	Luo et al. (2016b)
	Applanatumol F (**319**)	–	Luo et al. (2016b)
	Applanatumol G (**320**)	–	Luo et al. (2016b)
	Applanatumol H (**321**)	–	Luo et al. (2016b)
	Applanatumol I (**322**)	–	Luo et al. (2016b)
	Applanatumol J (**323**)	–	Luo et al. (2016b)
	Applanatumol K (**324**)	–	Luo et al. (2016b)
	Applanatumol L (**325**)	–	Luo et al. (2016b)
	Applanatumol M (**326**)	–	Luo et al. (2016b)
	Applanatumol N (**327**)	–	Luo et al. (2016b)
	Applanatumol O (**328**)	–	Luo et al. (2016b)
	Applanatumol P (**329**)	–	Luo et al. (2016b)
	Applanatumol Q (**330**)	–	Luo et al. (2016b)
	Applanatumol R (**331**)	–	Luo et al. (2016b)
	Applanatumol S (**332**)	–	Luo et al. (2016b)
	Applanatumol T (**333**)	–	Luo et al. (2016b)
	Applanatumol U (**334**)	–	Luo et al. (2016b)
	Applanatumol V (**335**)	–	Luo et al. (2016b)
	Applanatumol W (**336**)	–	Luo et al. (2016b)
	Applanatumol X (**337**)	–	Luo et al. (2016b)

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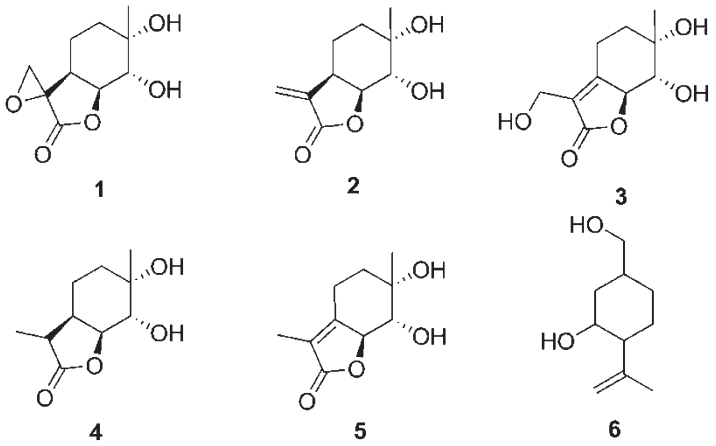
Table 9.1 (continued)

Fungi species	Compounds	Bioactivities	References
	Applanatumol Y (**338**)	–	Luo et al. (2016b)
	Applanatumol Z (**339**)	–	Luo et al. (2016b)
	Applanatumol Z1 (**340**)	–	Luo et al. (2016b)
	Applanatumol Z2 (**341**)	–	Luo et al. (2016b)
Ganoderma capense	Ganocapensin A (**346**)	Antioxidant effects	Peng et al. (2016)
	Ganocapensin B (**347**)	Antioxidant effects	Peng et al. (2016)
	Ganomycin E (**348**)	Antioxidant effects	Peng et al. (2016)
	Ganomycin F (**349**)	Antioxidant effects	Peng et al. (2016)
	Fornicin E (**350**)	Antioxidant effects	Peng et al. (2016)
Ganoderma lingzhi	Spirolingzhine A (**248**)	Affect NSC cell cycle progression	Yan et al. (2015a)
	Spirolingzhine B (**249**)	–	Yan et al. (2015a)
	Spirolingzhine C (**250**)	–	Yan et al. (2015a)
	Spirolingzhine D (**251**)	–	Yan et al. (2015a)
	Lingzhine A (**252**)	–	Yan et al. (2015a)
	Lingzhine B (**253**)	–	Yan et al. (2015a)
	Lingzhine C (**254**)	–	Yan et al. (2015a)
	Lingzhine D (**255**)	–	Yan et al. (2015a)
	Lingzhine E (**256**)	–	Yan et al. (2015a)
	Lingzhine F (**257**)	–	Yan et al. (2015a)
	Lingzhilactone A (**258**)	–	Yan et al. (2015b)
	Lingzhilactone B (**259**)	Inhibit ROS generation	Yan et al. (2015b)
	Lingzhilactone C (**260**)	–	Yan et al. (2015b)

Armillaria mellea	5′-Methoxy-armillasin (**382**)	–	Li et al. (2016b)
	5-Hydroxyl-armillarivin (**383**)	Cytotoxicity	Li et al. (2016b)
	Armillaridin (**384**)	Cytotoxicity	Li et al. (2016b)
	Armillartin (**385**)	Cytotoxicity	Li et al. (2016b)
	Armillarin (**386**)	–	Li et al. (2016b)
	Melleolide B (**387**)	–	Li et al. (2016b)
	Armillarilin (**388**)	Cytotoxicity	Li et al. (2016b)
	Armillasin (**389**)	Cytotoxicity	Li et al. (2016b)
	Armillarigin (**390**)	Cytotoxicity	Li et al. (2016b)
	Melleolide (**391**)	Cytotoxicity	Li et al. (2016b)
Neolentinus lepideus	5-Methoxyisobenzofuran-4,7(1H,3H)-dioneone (**392**)	Inhibition of nitric oxide production	Li et al. (2013b)
	1,3-Dihydroisobenzofuran-4,6-diol (**393**)	Antioxidant activity	Li et al. (2013b)
		Inhibition of nitric oxide production	
	394	Inhibition of nitric oxide production	Li et al. (2013b)
Lepista sordida	Lepistamide A (**403**)	–	Chen et al. (2011)
	Lepistamide B (**404**)	–	Chen et al. (2011)
	Lepistamide C (**405**)	–	Chen et al. (2011)
	Diatretol (**406**)	–	Chen et al. (2011)

"–" means the compound showed no bioactivity or was not studied for biological activity

production in lipopolysaccharide-activated macrophages, with an IC_{50} value of 81.8, 88.8, 80.4, 65.6, and 72.8 μM, respectively (Wang et al. 2013a). A monoterpenoid, 5-(hydroxymethyl)-2-(prop-1-en-2-yl) cyclohexanol (**6**), was isolated from the fruiting body of *Flammulina velutipes* (Cai et al. 2013).

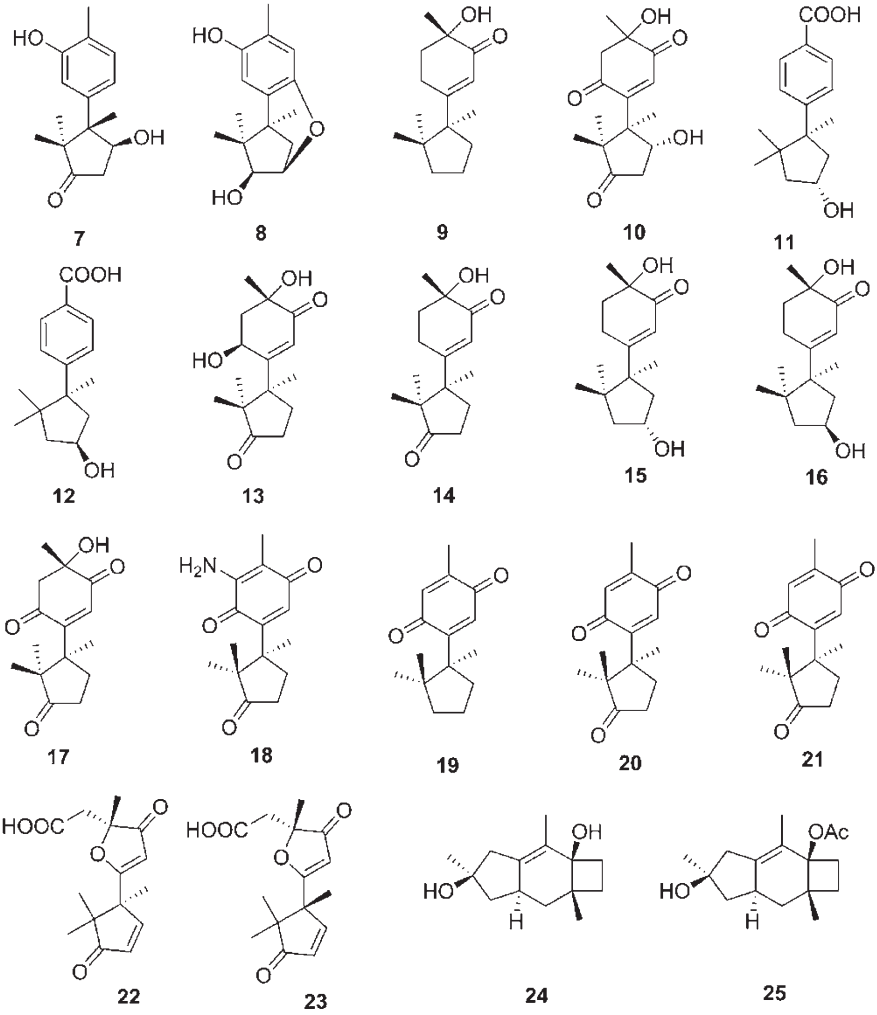


9.2.2 Sesquiterpenoids

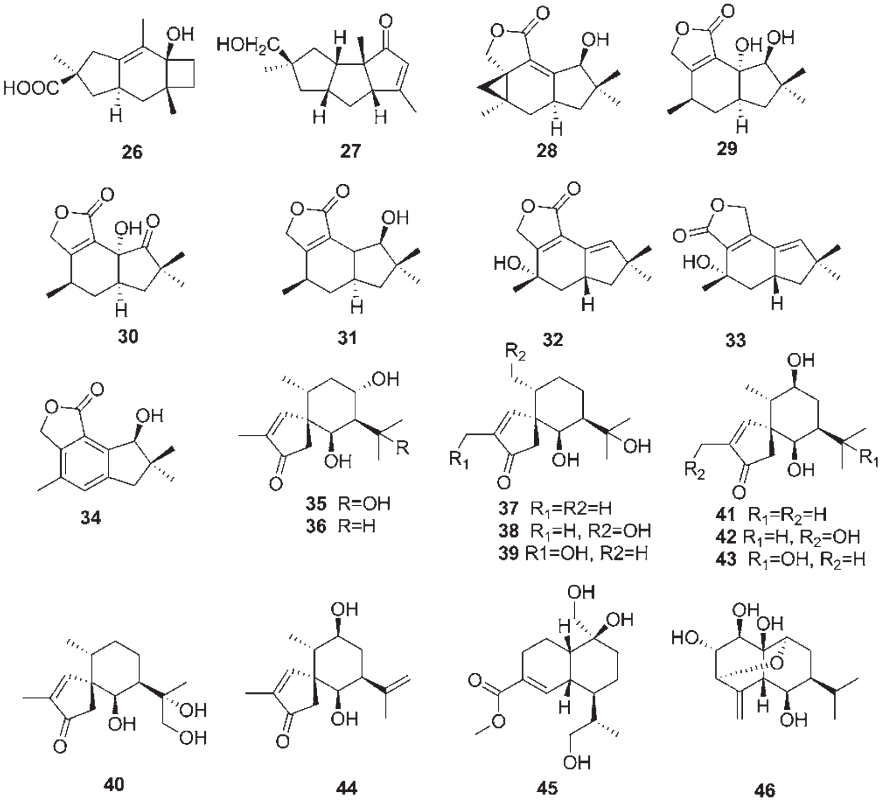
9.2.2.1 *Flammulina velutipes*

F. velutipes is a rich source of sesquiterpenoids with the various skeleton and interesting medicinal properties. More than 40 sesquiterpenoids have been obtained in recent years. Twelve new cuparene-type sesquiterpenes, flamvelutpenoids A–F (**7–12**) and enokipodins E–J (**13–18**), and three known sesquiterpenoids, 2,5-cuparadiene-1,4-dione (**19**) and enokipodins B (**20**) and D (**21**), were isolated from the solid culture of *F. velutipes* (Wang et al. 2012a, b; Tao et al. 2016a). Flamvelutpenoids A–D (**7–10**) showed weak antibacterial activity against *Escherichia coli*, *Bacillus subtilis*, and methicillin-resistant *Staphylococcus aureus* with MIC values larger than 100 μM (Wang et al. 2012a). Enokipodins F–G (**14–15**) and enokipodin I (**17**) showed weak antifungal activity against *Aspergillus fumigatus*; compounds **18–21** showed both moderate cytotoxicity against the human tumor cell lines (HepG2, MCF-7, SGC7901, and A549) and antioxidant activity in DPPH scavenging assay (Wang et al. 2012b). Flammufuranones A (**22**) and B (**23**) are two *seco*-cuparane sesquiterpenoids which may share a common precursor with cuparene-type sesquiterpene and biosynthesized from 1,6-cyclization (Tao et al. 2016a). Sterpurols A (**24**) and B (**25**), two new sterpurane sesquiterpenes, and sterpuric acid (**26**), a known sterpurane sesquiterpene, were isolated from the solid culture of *F. velutipes* (Wang et al. 2012b). Eight sesquiterpenoids including flammulinol A (**27**) with a new carbon skeleton and flammulinolides A–G (**28–34**), seven isolactarane-related norsesquiterpenes, were obtained from *F. velutipes*

cultivated on cooked rice (Wang et al. 2012c). Flammulinolides A–B (**28–29**) and F (**33**) showed strong cytotoxicity against KB cell line with the IC_{50} of 3.9, 3.6, and 4.7 μM, respectively. Flammulinolide C (**30**) showed strong cytotoxicity against HeLa cell line with the IC_{50} of 3.0 μM. Ten new sesquiterpenes with nor-eudesmane skeletons, flammuspirones A–J (**35–44**), as well as two new cadinene sesquiterpenes, 7,13,14-trihydroxy-4-cadinen-15-oic acid methyl ester (**45**) and 1,2,6,10-tetrahydroxy-3,9-epoxy-14-nor-5(15)-eudesmane (**46**), were obtained from the ethyl



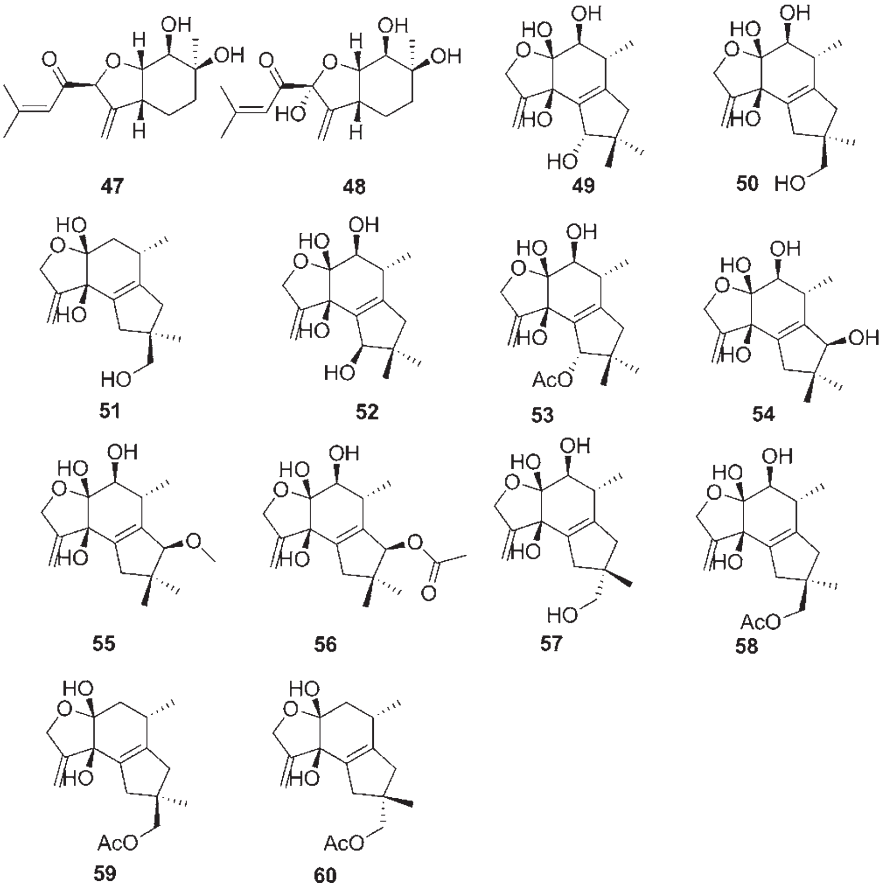
acetate extract of the solid culture of *F. velutipes* which is a wild strain collected in Yunnan province of China (Tao et al. 2016a). Among these compounds, compounds **35**, **37**, and **45**–**46** were found to inhibit the HMG-CoA reductase (HMGR) with IC_{50} of 114.7, 77.6, 55.5, and 87.1 μM, respectively. Compounds **37–39**, **42**, **44** and **46** showed DPP-4 inhibitory activity with IC_{50} of 75.9, 83.7, 70.9, 79.7, 80.5, and 74.8 μM, respectively. Identification of more than 40 sesquiterpenes with diverse skeletons and bioactivity provided evidence for the future application of *F. velutipes* as a functional food.



9.2.2.2 *Pleurotus cystidiosus*

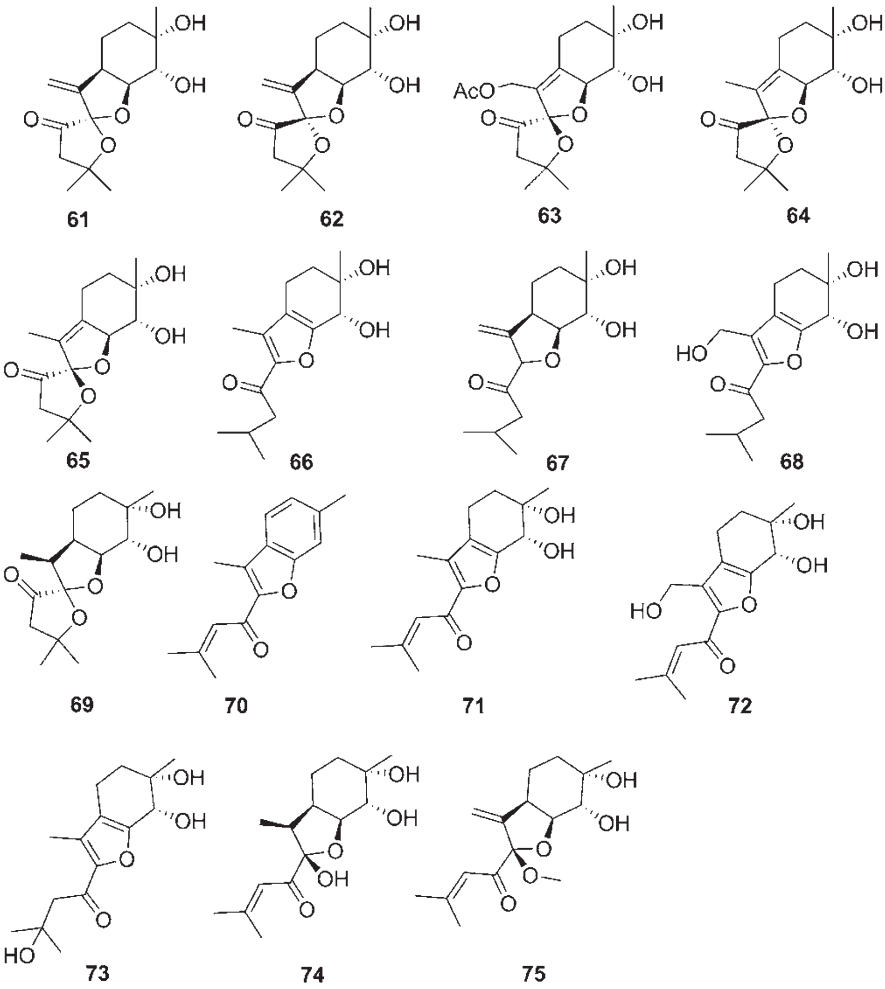
Pleurotons A–B (**47–48**), two bisabolane-type sesquiterpenoids, and clitocybulols D–F (**49–51**), three clitocybulol derivatives, were isolated from the ethyl acetate extract of the solid culture of *P. cystidiosus* (Zheng et al. 2015). Compounds **47–51** showed significant cytotoxicity against two human prostate cancer DU-145 and C42B cells. The IC_{50} of compounds **47–51** was 174, 28, 233, 162, and 179 nM, respectively, against the DU-145 cell and was 104, 52, 163, 120, and 119 nM, respectively, against the C42B cell. A further chemistry investigation of the solid

culture of the *P. cystidiosus* led to the identification of clitocybulols G–O (**52**–**60**) (Tao et al. 2016b). Clitocybulols G (**52**) and L (**57**) exhibited moderate inhibitory activity against protein tyrosine phosphatase 1B (PTP1B) with IC_{50} values of 36.0, 49.5, and 38.1 μM, respectively. All compounds had no significant inhibition against α-glucosidase, sucrose, and maltase.



9.2.2.3 *Pleurotus cornucopiae*

Pleurospiroketals A–E (**61–65**), five new sesquiterpenes, as well as three related sesquiterpenes (**66–68**) were obtained from the solid culture of *P. cornucopiae* (Wang et al. 2013b). Compound pleurospiroketals A–C (**61–63**) showed inhibitory activity against nitric oxide production in lipopolysaccharide-activated macrophages with IC_{50} values of 6.8, 12.6, and 20.8 μM, respectively. Compounds **66** and **68** exhibited slight growth inhibition against HeLa cells (IC_{50} values of 36.0 and 70.6 μM) and HepG2 (IC_{50} values of 68.6 and 76.8 μM).



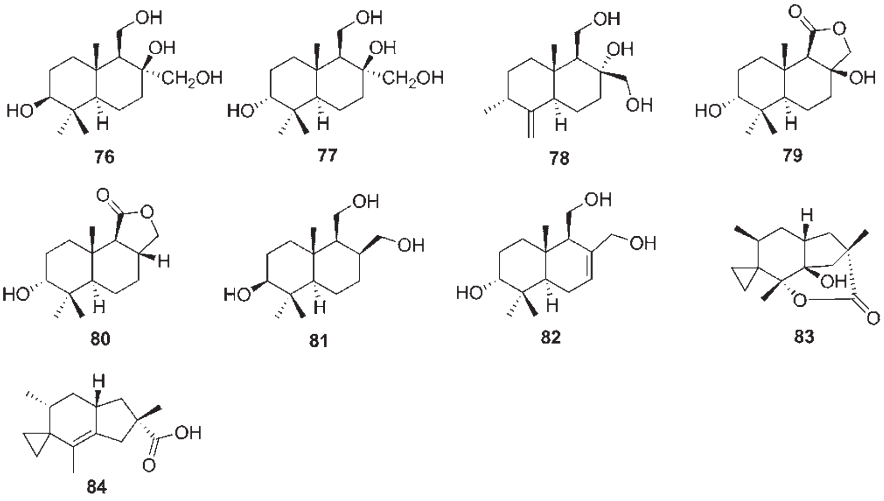
9.2.2.4 *Pleurotus citrinopileatus*

Seven new sesquiterpenes, pleurospiroketal F (**69**) and pleurotins A–F (**70**–**75**), as well as a known sesquiterpene pleuroton B (**48**), were obtained from the solid culture of *P. citrinopileatus* (Tao et al. 2016c). Pleurotins A (**70**) and E (**74**) exhibited inhibitory activity on PTP1B with IC_{50} of 32.1 μM and 30.5 μM, respectively.

9.2.2.5 *Laetiporus sulphureus*

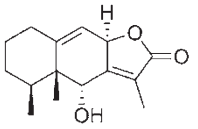
Seven new drimane-type sesquiterpenoids, sulphureuines B–H (**76–82**), were isolated from cultures of mushroom *Laetiporus sulphureus* (He et al. 2015a). Sulphureuine B (**76**) induces apoptosis in glioma cells through endoplasmic reticulum stress, mitochondrial, and death receptor signaling pathways. Two illudin-type

sesquiterpenoids, phellinuin J (**83**) and sulphureuine A (**84**), were obtained from the fermentation extract of *L. sulphureus* (He et al. 2015b). The two compounds were purposely evaluated for their cytotoxicity against HL-60, SMMC-7721, A549, MCF-7, and SW480 cell lines. Unfortunately, no significant inhibitory activity was found.



9.2.2.6 *Xylaria nigripes*

Xylaria nigripes has long been used as a traditional Chinese medicine (TCM) for enhancing memory, immunity, and hematopoiesis, treating insomnia and trauma, and as a diuretic, nerve tonic, and antidepressant (Liang et al. 2011; Ko et al. 2011; Zhao et al. 2014). Six new eremophilane-type sesquiterpenes, nigriterpenes A–F (**85–90**), were isolated from the ethyl acetate extracts of the fermented broths of termite nest-derived *X. nigripes* (Chang et al. 2017). These compounds were evaluated against lipopolysaccharide-induced inducible nitric oxide synthase (iNOS), cyclooxygenase-2 (COX-2) expression, and NO production in murine brain microglial BV-2 cells. Nigriterpene C (**87**) exerted significant inhibitory effects on two induced enzymes and NO production without any significant cellular toxicity. Nigriterpene C (**87**) exhibited concentration-dependent inhibition on NO production and iNOS and COX-2 expression with IC_{50} values of 21.7 ± 4.9, 8.1 ± 2.3, and 16.6 ± 5.5 μM, respectively. The results indicated that the potential anti-inflammatory effects of nigriterpene C (**87**) on murine brain microglial BV-2 cells might provide a rationale for the traditional medical uses of *X. nigripes* for treating insomnia and depression.



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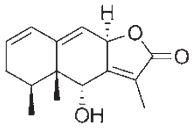

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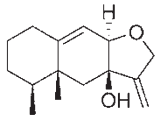

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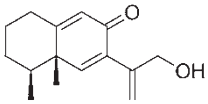

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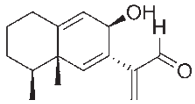

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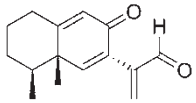

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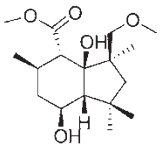
9.2.2.7 *Boletus edulis*

Three non-isoprenoid botryane sesquiterpenoids, named boledulins A–C (**91–93**), were isolated from the cultures of basidiomycete *B. edulis* (Feng et al. 2011). Boledulin A (**91**) exhibited moderate inhibitory effects on HL-60, SMMC-7721, A-549, MCF-7, and SW480 with IC_{50} values of 2.6, 8.4, 8.3, 3.4, and 3.5 μM, respectively.



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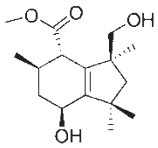

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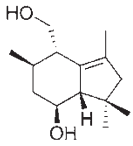

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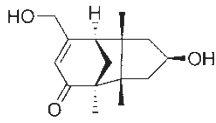

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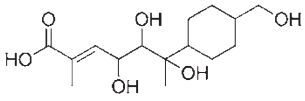

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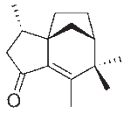

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9.2.2.8 *Inonotus vaninii*

I. vaninii has been used in Chinese folk medicine as "sang huang" for the treatment of cancer, diabetes, liver, and heart diseases and stomach ailments in Northeastern China (Dai et al. 2010). A novel sesquiterpene, inonolane A (**94**), was isolated from the EtOAc extract of the medicinal fungus *I. vaninii* (Yang et al. 2013b). Inonolane A (**94**) represents the first bisabolane-type sesquiterpene from the genus *Inonotus*.

9.2.2.9 *Ganoderma sinense*

Ganosinensine (**95**), a new sesquiterpene, was isolated from the fruiting bodies of the fungus *G. sinense* (Liu et al. 2012).

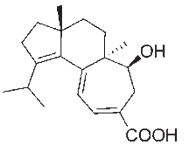
9.2.2.10 *Dictyophora indusiata*

A sesquiterpene antibiotic, albaflavenone (**96**), was isolated from the dried fruiting body of *D. indusiata* by solvent extraction and column chromatography (Huang et al. 2011). The content of albaflavenone (**96**) in the dried fruiting body of *D. indusiata* was quantified by GC through an external standard method to be about 0.0063%. Albaflavenone (**96**) has a camphor-like odor.

9.2.3 Diterpenoids

9.2.3.1 *Cyathus* spp.

The species belonging to the genus *Cyathus* (*Nidulariaceae* family) are recognized as prolific producers of bioactive cyathane diterpenoids with a unique [5-6-7] tricyclic ring skeleton. Cyathane diterpenoids represent a group of natural products with great diversity in both structure and bioactivity (Shen et al. 2009). Five novel cyathane diterpenes, cyathins D–H (**97–101**), as well as three known diterpenes, neosarcodonin O (**102**), cyathatriol (**103**), and 11-O-acetylcyathatriol (**104**), were isolated from the solid culture of *Cyathus africanus* (Han et al. 2013). Compounds **99**, **101**, **102**, and **104** showed potent inhibition of nitric oxide production in lipopolysaccharide-activated macrophages with an IC_{50} value of 2.57, 1.45, 12.0, and 10.73 μM, respectively. Neosarcodonin O (**102**) and 11-O-acetylcyathatriol (**104**) showed strong cytotoxicity against HeLa and K562 cell lines with the IC_{50} value less than 10 μM. Cyathin R (**105**), a new cyathane diterpenoid, was isolated from the solid culture of *C. africanus* (Huang et al. 2015). A further chemistry investigation of the solid culture of the *C. africanus* led to the identification of three new cyathane diterpenoids, cyathin T (**106**), cyathin V (**107**), and cyathin W (**108**) (Han et al. 2015). Cyathins T (**106**) and W (**108**) showed moderate inhibition against nitric oxide production in lipopolysaccharide-activated macrophages with an IC_{50} value of 88.87 and 80.07 μM, respectively. In cytotoxicity assay, cyathin W (**108**) showed weak cytotoxicity against K562 cell line with the IC_{50} value of 12.1 μM. Cyathin Q (**109**), a new cyathane-type diterpene, was obtained from the culture of the fungus *C. africanus* by bioactivity-guided separation (He et al. 2016). The bioactivity evaluation shows that cyathin Q (**109**) exhibited anticancer activity via induction of mitochondria- and autophagy-dependent apoptosis in HCT116 cells. Cyathin I (**110**), a new cyathane diterpene, and two related diterpenes, (12R)-11a,14a-epoxy-13a,14b,15-trihydroxycyath-3-ene (**111**) and erinacine I (**112**), were obtained from the fermentation broth of *Cyathus hookeri* (Xu et al. 2013). Compounds **110–112** showed inhibition against nitric oxide production in macrophages with an IC_{50} value of 15.5, 52.3, and 16.8 μM, respectively. Seven new cyathane-type diterpenes, cyathins J–P (**113–119**), and two known diterpenes (**120–121**) were isolated from the solid culture of *Cyathus gansuensis* (Wang et al. 2014a). Bioactivity screening indicated that cyathins J–K (**113–114**), M (**116**), and compound **120** showed moderate inhibitory activity against NO production in lipopolysaccharide-activated macrophages with an IC_{50} value of 42, 78, 80, and 16 μM, respectively. A chemical



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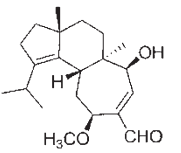

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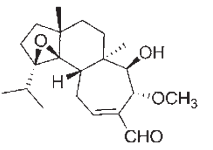

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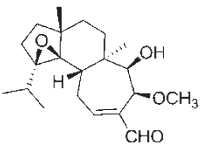

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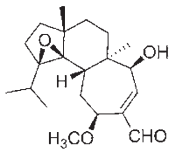

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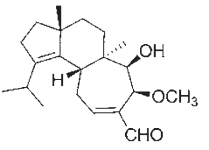

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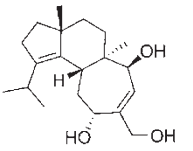

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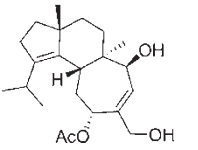

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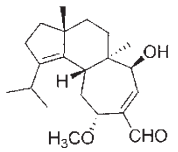

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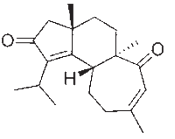

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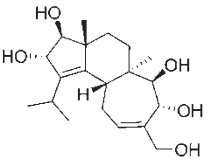

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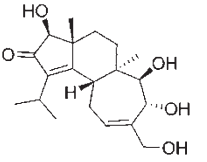

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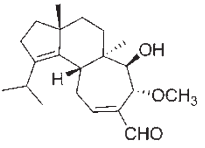

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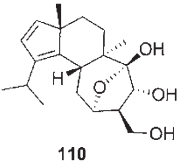

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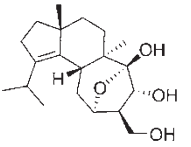

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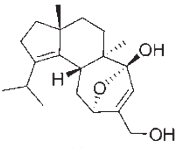

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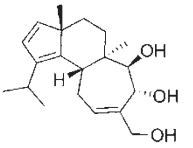

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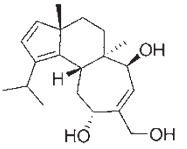

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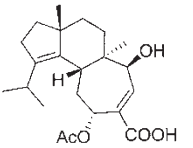

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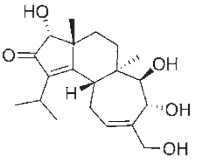

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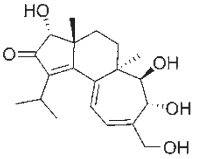

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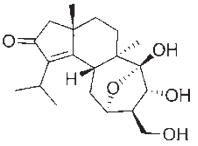

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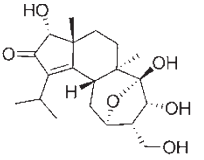

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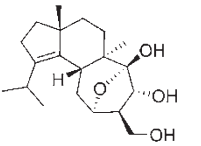

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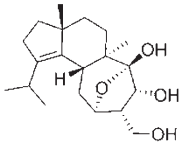

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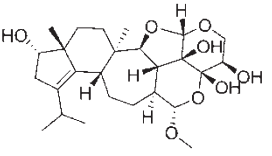

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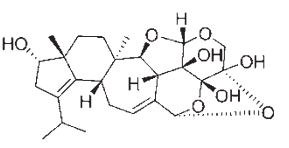

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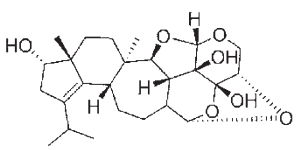
investigation of the solid culture of *Cyathus striatus* led to the identification of six new cyathane xylosides, striatoids A–F (**122–127**) (Bai et al. 2015). The bioactivity evaluation shows that striatoids A–F (**122–127**) dose-dependently enhanced nerve growth factor (NGF)-mediated neurite outgrowth.

9.2.3.2 *Hericium erinaceus*

The fruiting bodies of this mushroom were used in Chinese folk medicine to treat the tumors of the digestive systems, such as esophageal, stomach, and duodenum cancers and hyperglycemia. The chemical constituents of *H. erinaceum* were widely investigated. Aromatic compounds and diterpenoids with various bioactivities have been isolated from *H. erinaceus*. A new diterpene (**128**) was isolated from the fungal mycelia of *H. erinaceus* by the tracking method of antibacterial activity (Zhang et al. 2015a). Compound **128** showed good cytotoxicity against tumor cell lines (K562 and HEP2) with $IC_{50} < 200$ μM.



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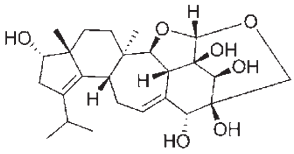

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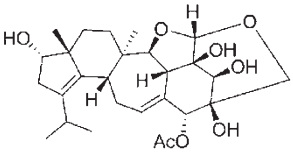

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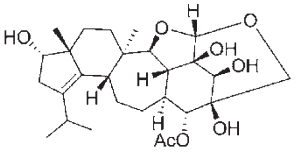

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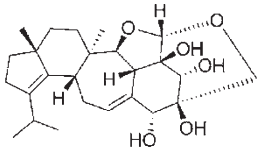

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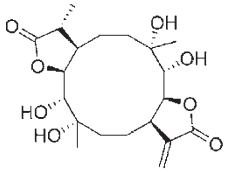

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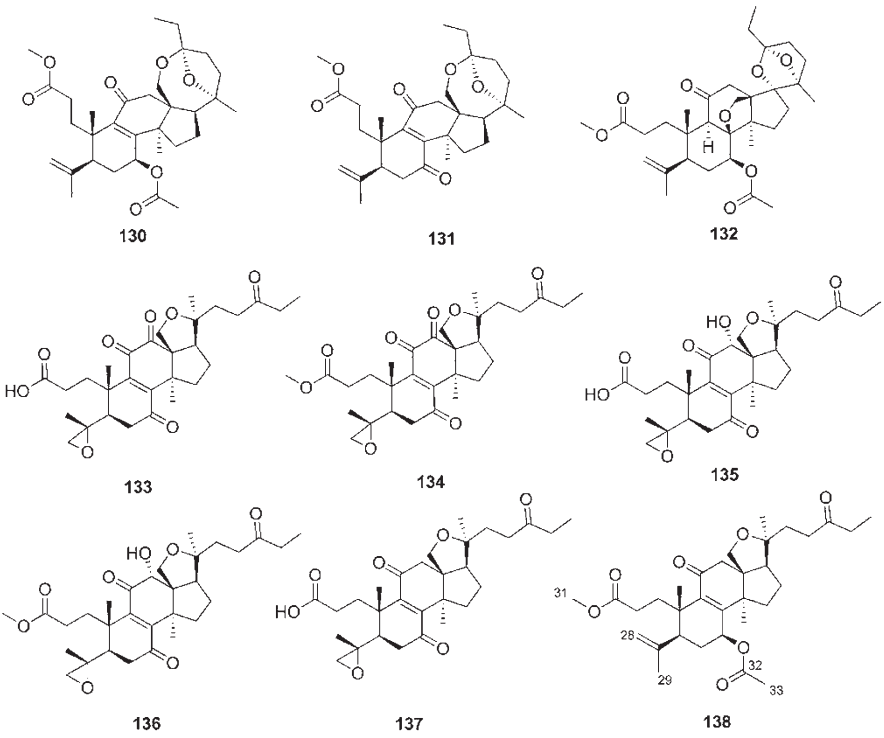
9.2.3.3 *Pleurotus eryngii*

Eryngiolide A (**129**), a new diterpenoid with unprecedented skeleton, was obtained from the mycelia of edible mushroom *P. eryngii* fermented on rice (Wang et al. 2012d). This compound was tested for their cytotoxic effects against two human cancer cell lines, HeLa and HepG2, using the MTT method. Eryngiolide A (**129**) showed moderate toxicities against two cell lines with IC_{50} values of 20.6 and 28.6 μM, respectively. This macrocyclic diterpene can be formed by a [6+6] cycloaddition from two molecules of geranyl pyrophosphate (GPP).



9.2.4 Triterpenoids

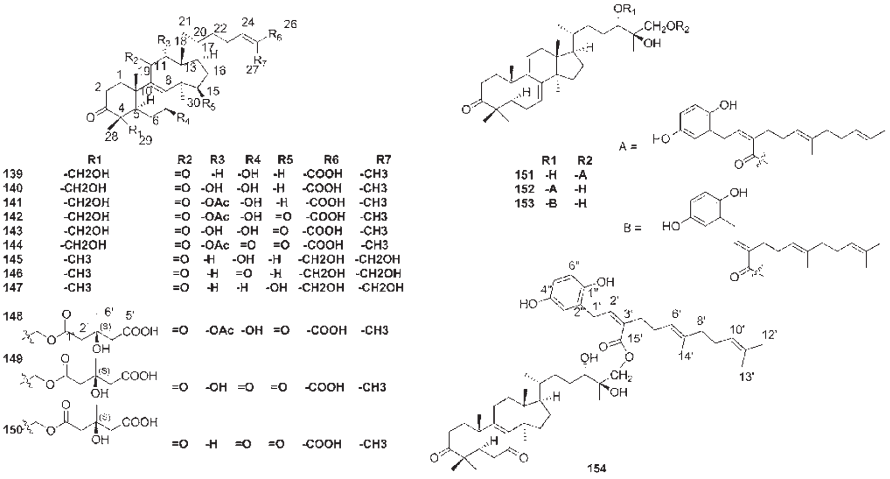
9.2.4.1 *Ganoderma boninense*

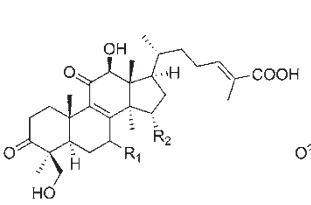
In a searching for new bioactive agents from medicinal mushrooms, the fruiting bodies of *G. boninense* collected from the Hainan province of China (Quinlan Nature Reserve) were chemically investigated. As a result, ganoboninketals A–C (**130–132**), three new nortriterpenes, were obtained from the fruiting bodies of *G. boninense* (Ma et al. 2014). Ganoboninketals A–C (**130–132**) exhibited significant antiplasmodial activity against *Plasmodium falciparum* with IC_{50} values of 4.0, 7.9, and 1.7 μM, respectively. Ganoboninones A–F (**133**–**138**), six new nortriterpenes, were also isolated from the fruiting bodies of the medicinal mushroom *G. boninense* (Ma et al. 2015). Ganoboninones A–B (**133–134**) and F (**138**) showed antimalarial effects with IC_{50} values of 27.36, 15.68, and 2.03 μM, respectively. In a transactivation assay, ganoboninketals A–C (**130–132**) and ganoboninone E (**137**) showed agonistic activity to LXRβ with an EC_{50} value of 8.32, 257.00, 86.70, and 203.00 nM, respectively.

9.2.4.2 *Ganoderma leucocontextum*

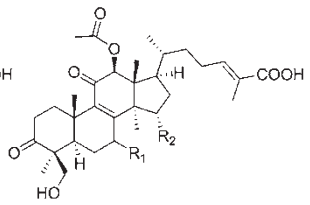
G. leucocontextum, also called "White Lingzhi" due to its white fleshy fruiting bodies, enjoys a strong reputation for being one of the top high-quality Lingzhi in China for its health function from folk usage. Chemical investigation of cultivated and wild *G. leucocontextum* led to the discovery of more than 50 triterpenoids with diverse bioactivity. Ganoleucoins A–P (**139–154**), 16 new lanostane triterpenes, were obtained from the cultivated fruiting bodies of *G. leucocontextum* (Wang et al. 2015a). Compounds **139**, **141**, **144**, and **148–152** exhibited strong inhibitory activity against HMG-CoA reductase. Compounds **139–140**, **144**–**145**, **148**, **150**, and **154** showed cytotoxicity against K562 cells with IC_{50} values in the range 10–20 μM.

A chemical research on the fruiting bodies of wild *G. leucocontextum* led to the identification of 18 new triterpenoids, leucocontextins A–R (**155–172**), (Zhao et al. 2016a). Leucocontextin R (**172**) presented weak cytotoxicity against K562 and MCF-7 cell lines with the IC_{50} of 20.35 and 28.66 μM, respectively. Leucocontextins S–X (**173–178**), six new triterpenoids, were obtained from the fruiting bodies of wild *G. leucocontextum* (Zhao et al. 2016b). The inhibitory activities against K562, SMMC-7721, and MCF-7 cell lines for leucocontextins S–X (**173–178**) were evaluated. Unfortunately, none of them showed significant activity.

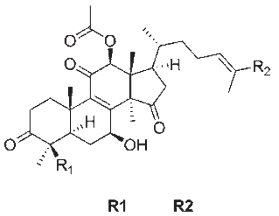




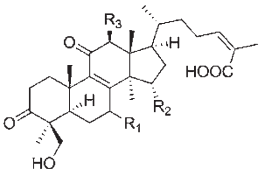
	R1	R2
155	β-OH	=O
156	β-OH	OH
157	α-OH	OH
158	=O	OH
162	H	OH



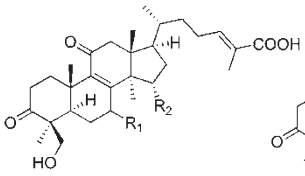
	R1	R2
164	β-OH	=O
165	α-OH	OH
166	=O	OH
167	=O	=O
168	H	OH



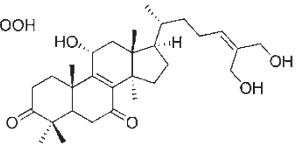
	R1	R2
169	CHO	COOH
170	CH2OH	COOMe



	R1	R2	R3
159	=O	=O	OH
171	α-OH	OH	OAc



	R1	R2
160	β-OH	OH
161	=O	=O
163	H	OH



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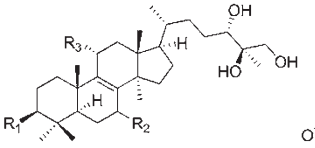
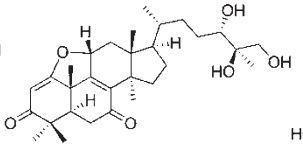


	R1	R2	R3
173	=O	=O	-OH
174	=O	β-OH	=O
175	-OH	=O	-OH



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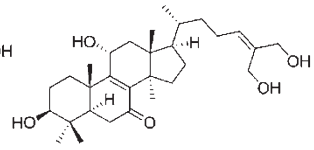

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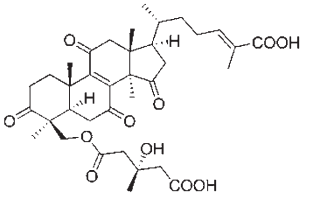

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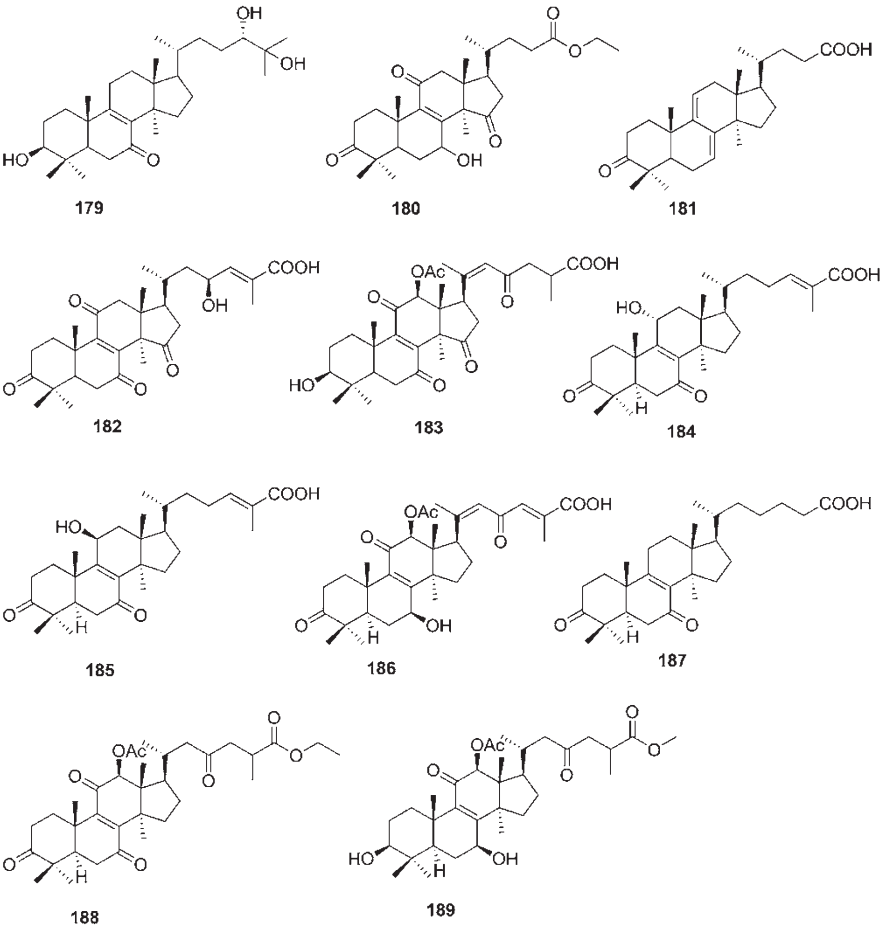
9.2.4.3 *Ganoderma lucidum*

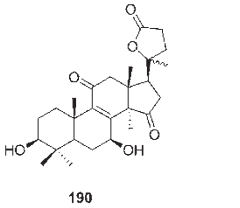
G. lucidum, a TCM called Lingzhi, is one of the most highly ranked herbal medicines by Asian people, whose fruiting body, mycelia, and spores were traditionally used as a folk medicine for treatment of debility and weakness, insomnia, hepatitis, cardiovascular diseases, cancer, etc. (Lin 2001; Gao and Zhou 2004; Lin and Zhang 2004). Modern research revealed the bioactivity components of *G. lucidum* to be triterpenes and polysaccharides, which were reported to possess antivirus (Li and

Wang 2006), anti-inflammation (Akihisa et al. 2007), antitumor (Nonaka et al. 2006), immunity-promoting (Zhu et al. 2007), and antidiabetic effects (He et al. 2006). In the latest 10 years, chemical investigation of the metabolites in *G. lucidum* led to identification of 11 new triterpenes, ganoderitriol M (**179**), ethyl lucidenate A (**180**), ethyl 7β-hydroxy-4,4,14α-trimethyl-3,11,15-trioxo-5α-chol-8-en-24-oate (**181**), 23S-hydroxy-3,7,11,15-tetraoxo-lanost-8,24E-diene-26-oic acid (**182**), 12β-acetoxy-3β-hydroxy-7,11,15,23-tetraoxo-lanost-8,20E-diene-26-oic acid (**183**), and compounds **184–189** (Chen et al. 2009; Li et al. 2013a; Zhang et al. 2011; Guan et al. 2008; Cheng et al. 2010). Ethyl lucidenate A (**180**) exhibited cytotoxicity against HL-60 and CA46 cell with IC_{50} values of 25.98 and 20.42 μgmL^{-1}, respectively (Li et al. 2013a). Compound **181** had NGF-like neuronal survival-promoting activities (Zhang et al. 2011). Compounds **182–183** exhibited cytotoxicity against four human tumor cell lines, p388, HeLa, BEL-7402, and SGC-7901, with the IC_{50} values in the range of 8–25 μM (Guan et al. 2008).



9.2.4.4 *Ganoderma sinense*

G. sinense, a well-known species of *Ganoderma*, is widely distributed in Yunnan province, in the southwest of China. Compared with *G. lucidum*, chemical studies on *G. sinense* have rarely been reported. Ganolactone B (**190**) and ganoderiol A triacetate (**191**), two novel lanostane-type triterpenes, were isolated from the fruiting bodies of *G. sinense* (Qiao et al. 2007). To further discover structurally diverse and biologically significant compounds from the *G. sinense*, three new triterpenoids, methyl ganosinensate A (**192**), ganosinensic acid A (**193**), and ganosinensic acid B (**194**), with an unusual four-membered ring produced by linkage of C-1 with C-11 were isolated from the fruiting body of *G. sinense* (Wang et al. 2010). In 2011, nine new triterpenoids ganosineniol A (**195**), ganosinoside A (**196**), ganoderic acid Jc (**197**), ganoderic acid Jd (**198**), ganodermatetraol (**199**), ganolucidic acid γa (**200**), ganolucidate F (**201**), ganoderiol J (**202**), and methyl lucidenate Ha (**203**) were isolated from the fruiting bodies of the fungus *G. sinense* (Liu et al. 2012). Among these compounds, ganoderic acid Jc (**197**) displayed selective inhibitory activity against HL-60 cells (IC_{50} = 8.30 μM). Ganodermatetraol (**199**) and ganolucidate F (**201**) showed induction ability of hPXR-mediated CYP3A4 expression.



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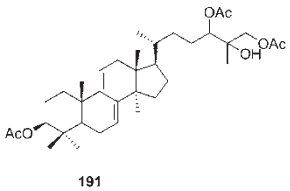

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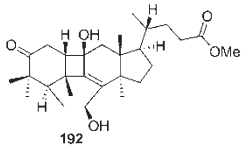

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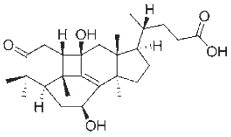

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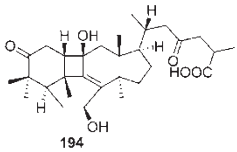

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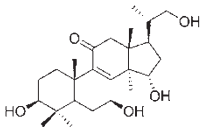

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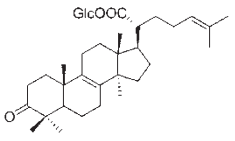

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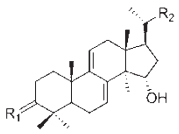
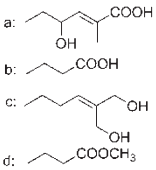


	R_1	R_2
197:	O	a
198:	O	b
199:	α-H,β-OH	c

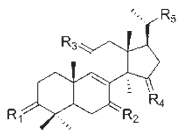


a:

b:

c:

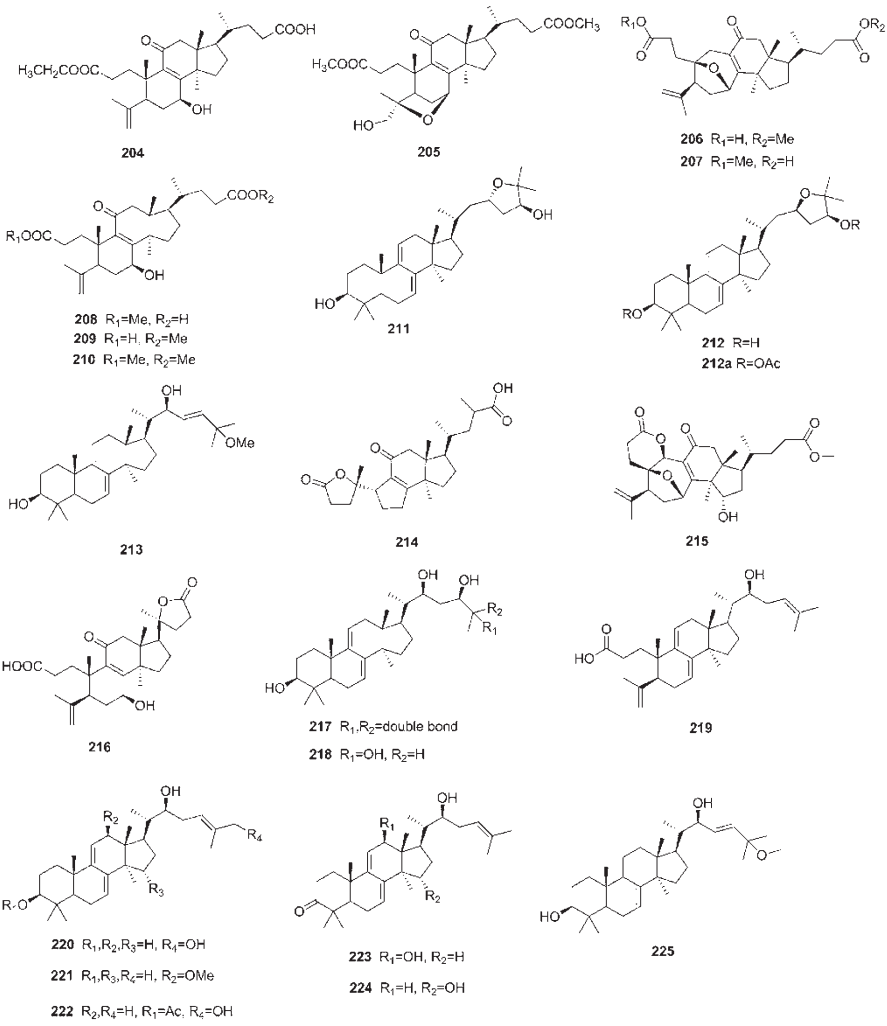
d:



	R_1	R_2	R_3	R_4	R_5	R_6
200:	α-H,β-OH	α-H,β-OH	O	α-OH,β-H	a	H
201:	α-H,β-OH	H	O	α-OH,β-H	a	H
202:	O	O	H	H	c	H
203:	α-H,β-OH	α-H,β-OH	O	O	d	OH

9.2.4.5 *Ganoderma cochlear*

G. cochlear has the same morphological characteristics as *G. sinense*, but the fungus stipe of *G. cochlear* lies in the back of the pileus. Initial phytochemical investigation on *G. cochlear* resulted in the identification of two new 3,4-secotrinorlanostane triterpenoids, fornicatin G (**204**) and H (**205**) (Peng et al. 2012). To discover additional biologically functional triterpenoids from *G. cochlear*, the chemical constitutes of *G. cochlear* were studied. As a result, cochlates A (**206**) and B (**207**), two novel trinorlanostanes with a 3,4-seco-9,10-seco-9,19-cyclo skeleton, as well as six new triterpenoids, fornicatins D–F (**208–210**) and ganodercochlearins A–C (**211–213**), were obtained from the fruiting bodies of *G. cochlear* (Peng et al. 2014a). Fornicatins D (**208**) and F (**210**) lowered the ALT and AST levels in HepG2 cells treated with H_2O_2, suggesting that both compounds could display in vivo hepatoprotective activities. In 2015, a rearranged hexanorlanostane triterpenoid featuring with a γ-lactone ring and a five-membered carbon ring, ganocochlearic acid A (**214**), and 11 new lanostane triterpenoids cochlate C (**215**), cochlearic acid A (**216**), ganodecochlearin D (**217**), ganodercochlearin E (**218**), cochlearic acid B (**219**), and ganodercochlearins F–K (**220–225**) were isolated from the fruiting bodies of *G. cochlear* (Peng et al. 2015a). Ganodercochlearins F–H (**220–222**) and J–K (**224–225**) showed moderate cytotoxic activities against five human tumor cell lines (HL-60, SMMC-7721, A-549, MCF-7, and SW480) with IC_{50} values ranging from 8 to 30 μM. Ganodecochlearin D (**217**) exhibited relatively potent cytotoxic activity against MCF-7 cells (IC_{50}: 9.15 μM), compared to the positive control (cisplatin, IC_{50}: 12.7 μM).



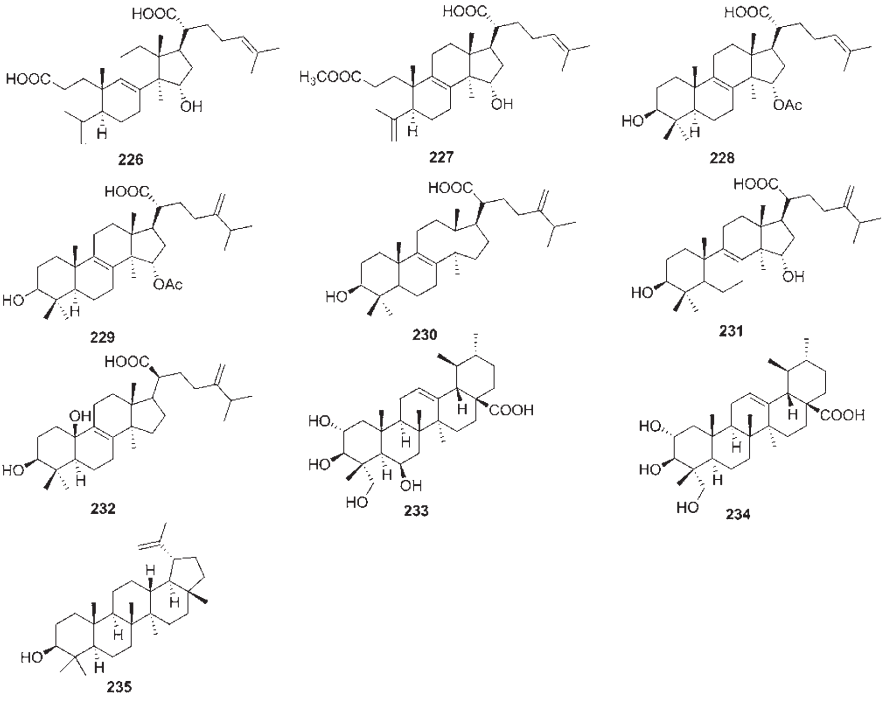
9.2.4.6 *Laetiporus sulphureus*

Two 3,4-seco-lanostane-type triterpenes, 15α-hydroxy-3,4-secolanosta-4(28),8,24-triene-3,21-dioic acid (**226**) and 5α-hydroxy-3,4-seco-lanosta-4(28),8,24-triene-3,21-dioic acid 3-methyl ester (**227**), and one lanostane triterpene 15α-acetoxylhyd roxytrametenolic acid (**228**) together with versisponic acid D (**229**) were isolated from the fruiting bodies of *L. sulphureus* (Yin et al. 2015). Compounds **226–229** were evaluated by MTT method for their cytotoxicities against five human cancer cell lines, breast cancer MCF-7, hepatocellular carcinoma SMMC-7721, human myeloid leukemia HL-60, colon cancer SW480, and lung cancer A-549. However, none exhibited inhibitory effects. From the EtOAc extracts of the same fungal culture broth, compounds **230** and **231** were obtained (He et al. 2015a). Compound **230**

showed moderate activities against four cells HL-60, SMMC-721, A-549, and SW-480, with IC_{50} values of 37.5, 14.8, 15.6, and 36.1 μM, respectively. Eburicoic acid (**232**) is the main bioactive component in the *L. sulphureus* (Wang et al. 2015b). Eburicoic acid (**232**) protected the gastric mucosa from gastric lesions morphologically and especially attenuated H^+/K^+-ATPase activity.

9.2.4.7 *Pleurotus eryngii*

2,3,6,23-Tetrahydroxy-urs-12-en-28-oic acid (**233**), 2,3,23-trihydroxyurs-12-en-28-oic acid (**234**), and lupeol (**235**) were identified from the EtOAc-soluble portion of *P. eryngii* extract (Xue et al. 2015). The three isolated compounds were evaluated for the proliferation inhibition activity against the human breast cancer cell line MCF-7 using the MTT assay. All of the compounds significantly inhibited MCF-7 cell proliferation. The IC_{50} values were 15.71, 48.00, and 66.89 μM, respectively. Compound **233** showed greater antitumor activity than compound **234**, indicating that the presence of an additional hydroxyl group at C-6 enhances the cytotoxic effect. Compounds **233–234**, with the carboxylic acid at C-28, showed slightly more potent inhibitory activities in MCF-7 cells than **235**, which lacks a carboxy group at C-28. These results suggest that a free carboxylic group at C-28 may be important to exert antiproliferative activity.



9.3 Meroterpenoids

Meroterpenoids are hybrid natural products of both terpenoid and nonterpenoid origin. They have attracted much attention due to their unusual structure features, wide range of bioactivities and interesting biosynthetic mechanisms (Geris and Simpson 2009). Based on the biosynthetic origins, meroterpenoids can be classified into two groups: polyketide-terpenoids and shikimate-terpenoids.

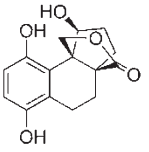
9.3.1 Shikimate-Terpenoids

9.3.1.1 *Ganoderma lucidum*

(+)-Lingzhiol (**236**) and (−)-lingzhiol (**237**), a pair of rotary door-shaped meroterpenoidal enantiomers, were isolated from *G. lucidum* (Yan et al. 2013). Lingzhiols (**236–237**) bears an unusual 5/5/6/6 ring system characteristic of sharing a C-3-C-7 axis. The biological evaluation showed that (+)-lingzhiol (**236**) or (−)-lingzhiol (**237**) could selectively inhibit the phosphorylation of Smad3 in TGF-β1-induced rat renal proximal tubular cells and activate Nrf2/Keap1 in mesangial cells under diabetic conditions. Further chemistry investigation on the fruiting body of *G. lucidum* led to the isolation of six new meroterpenoids, chizhines A–F (**238–243**) (Luo et al. 2015a). Chizhines A–F (**238–243**) are isolated as racemic mixtures. Chiral HPLC was utilized to obtain the individual (+)- and (−)-antipodes of these substances. The renoprotective effects of chizhines A–F (**238–243**) were evaluated by using the ELISA technique and high glucose-induced rat mesangial cells. The results show that the individual enantiomers of these substances significantly inhibit monocyte chemotactic protein 1 (MCP-1) and fibronectin production in a dose-dependent manner. Lingzhifuran A (**244**) and lingzhilactones D–F (**245–247**), four new phenolic meroterpenoids, were isolated from the fruiting bodies of *G. lucidum* (Ding et al. 2016). Lingzhifuran A (**244**) and lingzhilactone D (**245**) could selectively inhibit TGF-β1-induced Smad3 phosphorylation in rat renal tubular epithelial cells, representing novel scaffolds of selective Smad3 activation inhibitors.

9.3.1.2 *Ganoderma lingzhi*

G. lingzhi is a valuable, edible, and medicinal fungus that has been widely used for the prevention and treatment of a broad range of diseases. Spirolingzhines A–D (**248–251**), four new meroterpenoids with aspiro[benzofuran-2,10-cyclopentane] motif, and lingzhines A–F (**252–257**), six new meroterpenoids with diverse ring systems, were isolated from the fruiting bodies of *G. lingzhi* (Yan et al. 2015a). (−)-Spirolingzhine A (**248**) was shown to affect NSC cell cycle progression using the 5-bromo-2-deoxyuridine (BrdU) incorporation assay. Three new lingzhilactones A–C (**258–260**) containing a fused lactone moiety were isolated from *G. lingzhi* (Yan et al. 2015b). Lingzhilactone B (**259**) could inhibit ROS generation in a dose-dependent manner; inhibit mRNA expression of collagen IV, fibronectin, and IL-6; and increase expression of Nrf2 in rat tubular epithelial cells. Furthermore, we found that compound **259** could reduce urinary albumin levels, abrogate myofibroblastic activation, and inhibit the phosphorylation of Smad3 in Adriamycin-induced mice.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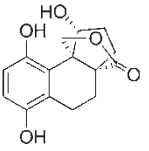
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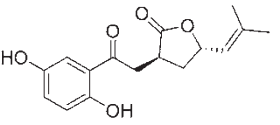
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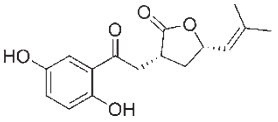
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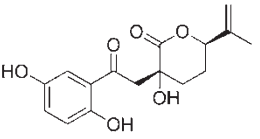
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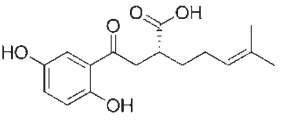
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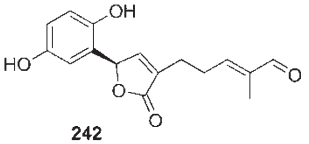
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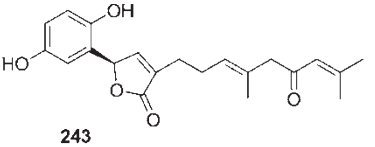
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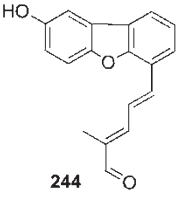
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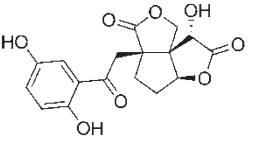
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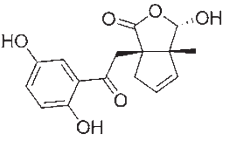
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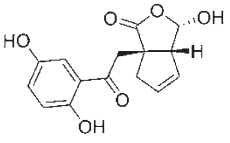
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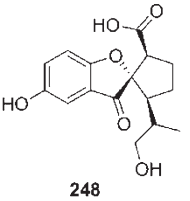
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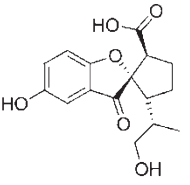
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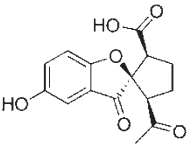
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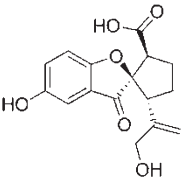
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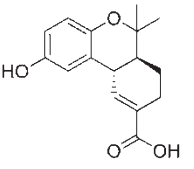
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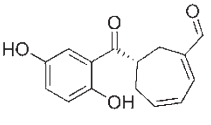
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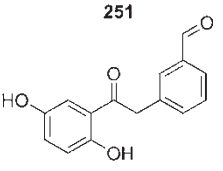
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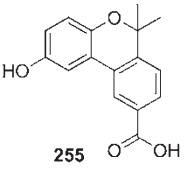
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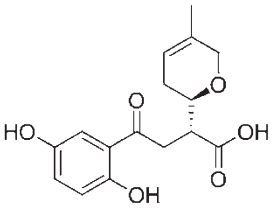

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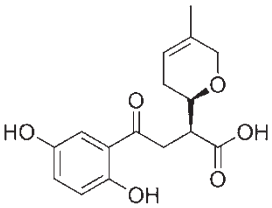

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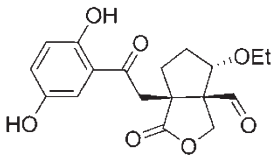

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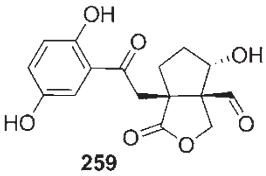

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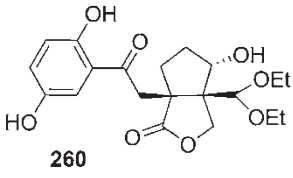
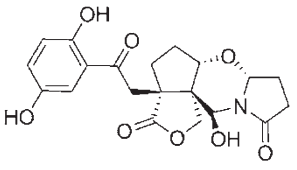


260

9.3.1.3 *Ganoderma sinensis*

(−)-Sinensilactam A (**261**) and (+)-sinensilactam A (**262**), novel hybrid metabolites possessing a unique 2Hpyrrolo[2,1-b] [1,3]oxazin-6(7H)-one ring system, were isolated from the fruit bodies of *G. sinensis* (Luo et al. 2015b). (−)-Sinensilactam A (**261**) was found to be a Smad3 phosphorylation inhibitor in TGF-β1-induced human renal proximal tubular cells. Zizhines A–F (**263–268**), six new meroterpenoid, were also isolated from the fruiting bodies of *G. sinensis* (Cao et al. 2016).



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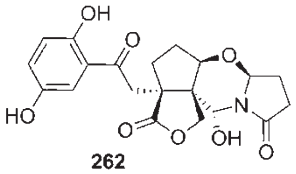

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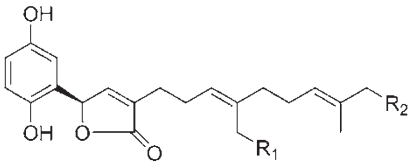
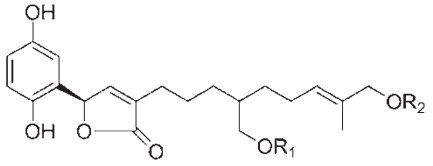
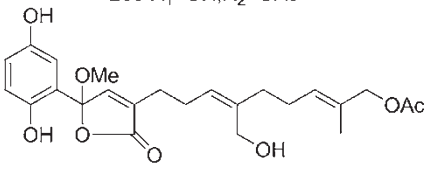


263 R_1=H, R_2=OH
264 R_1=OAc,R_2=OH
266 R_1=OH,R_2=OAc



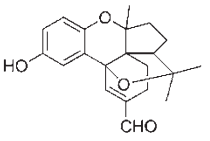
265 R_1=Ac, R_2=H
267 R_1=H,R_2=Ac



268

9.3.1.4 *Ganoderma cochlear*

Four pairs of new polycyclic-meroterpenoid enantiomers, ganocins A–C (**269–271**) possessing a spiro[4,5]decane ring system, along with ganocin D (**272**) with an eight-membered ring, were isolated from the fruiting bodies of *G. cochlear* (Peng et al. 2014b). Ganocin D (**272**) had weak anti-AChE activity with an inhibition of 32% (50 μM). (+)- and (−)-Cochlearols A (**273**) and B (**274**), two meroterpenoids with novel polycyclic skeletons, were isolated from the fruiting bodies of the fungus *G. cochlear* (Dou et al. 2014). Biological studies showed that (−)-cochlearol B (**274**) is a strong inhibitor of p-Smads, exhibiting renoprotective activities in TGF-β1-induced rat renal proximal tubular cells. Cochlearoids A–E (**275–279**) and cochlearines A (**280**) and B (**281**) were obtained from *G. cochlear* (Zhou et al. 2015). Compounds (+)-**275**, (−)-**278**, and (±)-**280** exhibited significantly inhibited $Ca_v3.1$ TTCC and showed noticeable selectivity against $Ca_v1.2$, $Ca_v2.1$, $Ca_v2.2$, and $K_v11.1$ (hERG) channels. Five novel meroterpenoids, ganoderin A (**282**) and ganocochlearins A–D (**283–286**), with the polycyclic skeleton and two new prenylated phenols, fornicin D (**287**) and ganomycin C (**288**) with a carbon chain, were isolated from the fruiting bodies of *G. cochlear* (Peng et al. 2015b). All compounds showed an antioxidant effect in radical scavenging assays. Six novel meroterpenoids cochlearoids F–K (**289–294**) were isolated by utilizing phytochemical approaches (Wang et al. 2016a). The biological evaluation shows that compounds **289–292** and **294** exhibit potent inhibitory activity on fibronectin overproduction in TGF-β1-induced HKC-8 cells.



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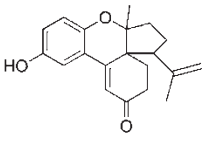

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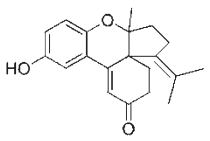

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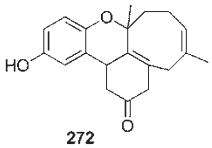

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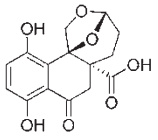

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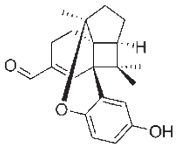

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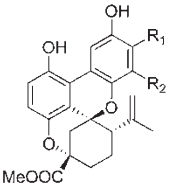
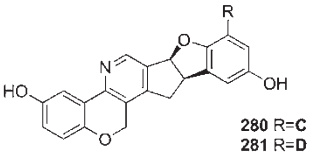
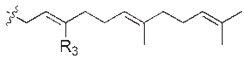


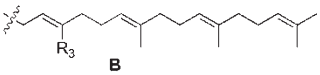
275 R_1=H, R_2=**A**, R_3=OAc
276 R_1=H, R_2=**A**, R_3=H
277 R_1=H, R_2=**B**,R_3=OH
278 R_1=**B**, R_2=H,R_3=OH
279 R_1=**A**, R_2=H,R_3=OAc



280 R=**C**
281 R=**D**



A



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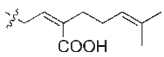
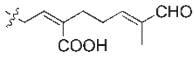
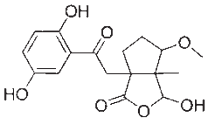


C



D



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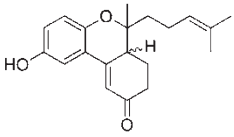

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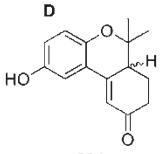

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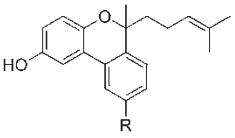
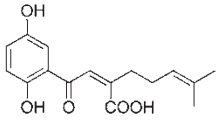


285 R=CHO
286 R=COOH



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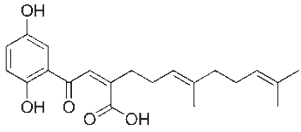

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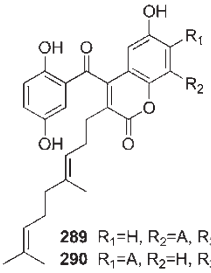
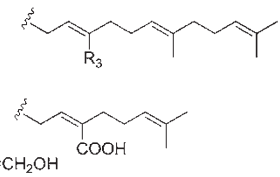
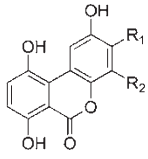


289 R_1=H, R_2=A, R_3=CH_2OH
290 R_1=A, R_2=H, R_3=CH_2OH

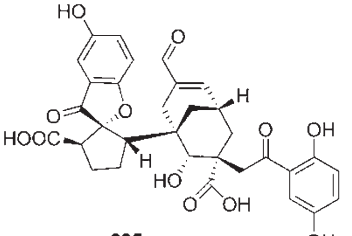




291 R1=H, R2=A, R3=COOH
292 R1=H, R2=A, R3=CH2OH
293 R1=A, R2=H, R3=CH2OH
294 R1=B, R2=H,

9.3.1.5 *Ganoderma applanatum*

Applanatumin A (**295**), a novel meroterpenoid dimer, was isolated from the fungus *G. applanatum* (Luo et al. 2015c). Applanatumin A exhibits potent antifibrotic activity in TGF-β1-induced human renal proximal tubular cells. Applanatumols A (**296**) and B [(±)-**297**], two unique meroterpenoids, respectively, with a novel spiro[benzofuran-2,2′-bicyclo[3.2.2] nonane] ring system and a naturally unusual dioxacyclopenta[cd]inden motif, were isolated from *G. applanatum* (Luo et al. 2016a). The biological evaluation shows that **296** and (+)-**297** are potent ECM inhibitors in TGF-β1-induced rat proximal tubular epithelial cells, suggesting that these metabolites could be used as novel structure templates for synthesizing more potent agents which are beneficial for CKD. (±)-Ganoapplanin (**298**), a pair of novel meroterpenoid enantiomers featuring an unprecedented dioxaspirocyclic skeleton constructed from a 6/6/6/6 tetracyclic system and an unusual tricyclo-[4.3.3.03′,7′] dodecane motif, were isolated from *G. applanatum* (Li et al. 2016a). Spiroapplanatumines A–Q (**299–315**), 17 new spiro meroterpenoids, respectively, bearing a 6/5/7 or 6/5/5 ring system, were isolated from the fruiting bodies of the fungus *G. applanatum* (Luo et al. 2017). Biological evaluation of spiroapplanatumines A–Q disclosed that spiroapplanatumines G–H (**305–306**) inhibited JAK3 kinase with IC_{50} values of 7.0 ± 3.2 and 34.8 ± 21.1 μM, respectively. Twenty-six new meroterpenoids, applanatumols C–Z (**316–339**), Z1 (**340**), and Z2 (**341**), were isolated from the fruiting bodies of *G. applanatum* (Luo et al. 2016b). Applanatumols C (**316**) was found to have COX-2 inhibitory effect with an IC_{50} value of 25.5 μM.



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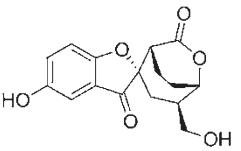

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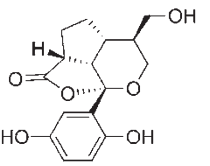

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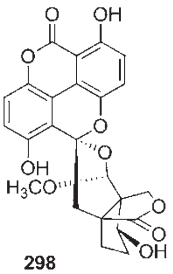

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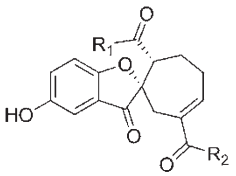
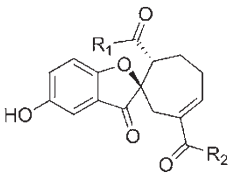
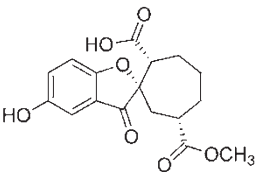




299 R_1=OH R_2=OH
301 R_1=OCH_3 R_2=OH
303 R_1=OH R_2=OCH_3
305 R_1=OH R_2=H
307 R_1=OCH_3 R_2=H

200 R_1=OH R_2=OH
302 R_1=OCH_3 R_2=OH
304 R_1=OH R_2=OCH_3
306 R_1=OH R_2=H



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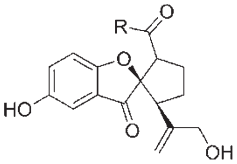
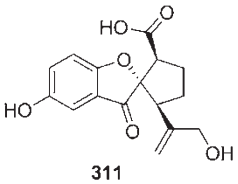


309 R=OCH3
310 R=OH



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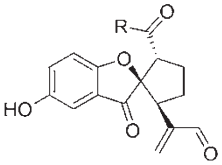
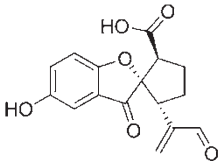


312a R=OH
313 R=OCH_3



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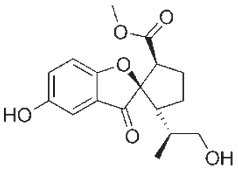

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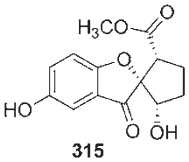

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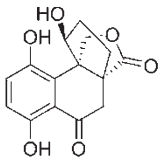

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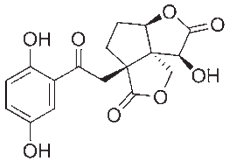

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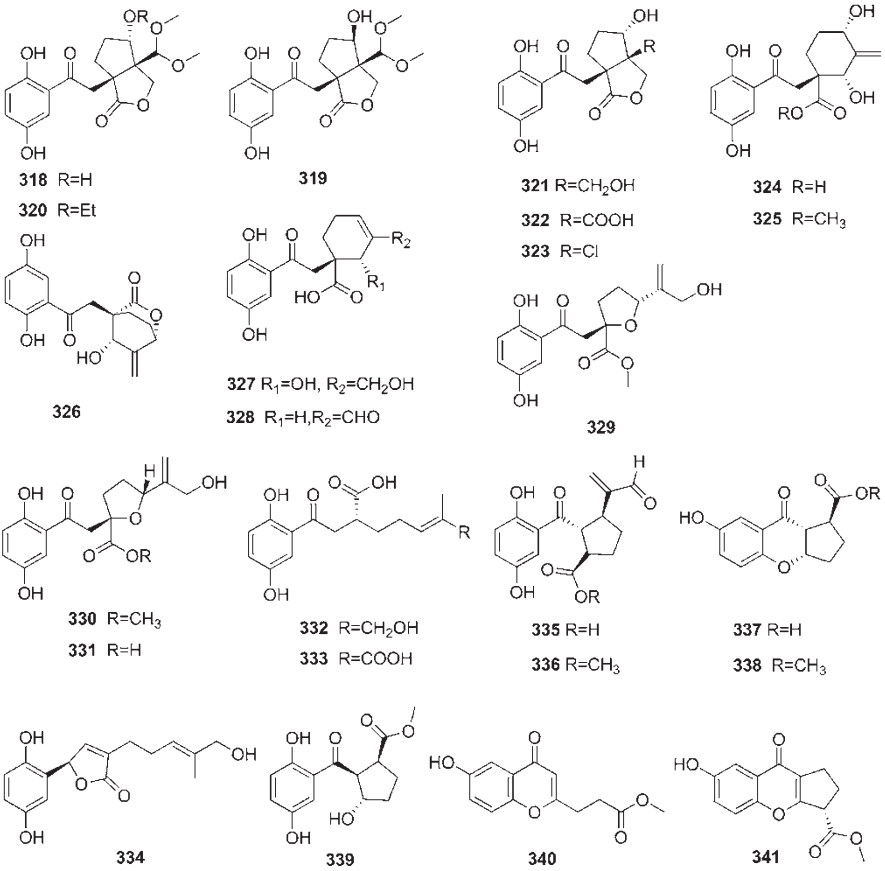
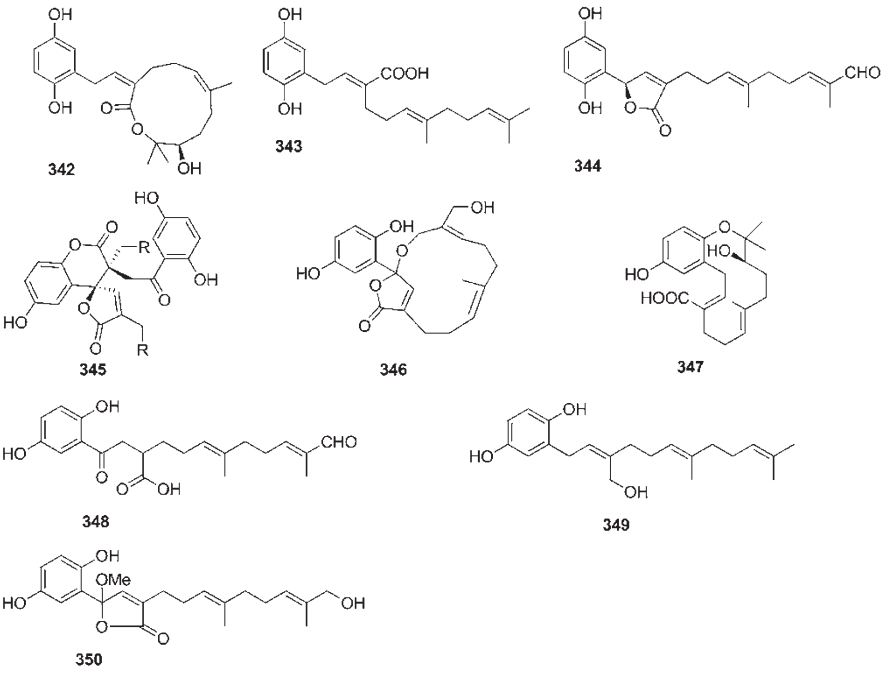


9.3.1.6 *Ganoderma leucocontextum*

Three new meroterpenoids, ganoleucins A–C (**342–344**), were isolated from the fruiting bodies of *G. leucocontextum* (Wang et al. 2016b). Ganoleucins A (**342**) and C (**344**) showed noncompetitive inhibitory activity against α-glucosidase. (+)- and (–)-Ganodilactone (**345**), a pair of novel meroterpenoid dimers possessing a unique 5′H-spiro[chroman-4,2′-furan]-2,5′-dione ring system, were discovered from the fruiting bodies of *G. leucocontextum* (Chen et al. 2016). (±)-, (+)-, and (–)-Ganodilactone (**345**) showed pancreatic lipase inhibitory activities and exhibited the IC_{50} values as 27.3, 4.0, and 2.5 μM, respectively.

9.3.1.7 *Ganoderma capense*

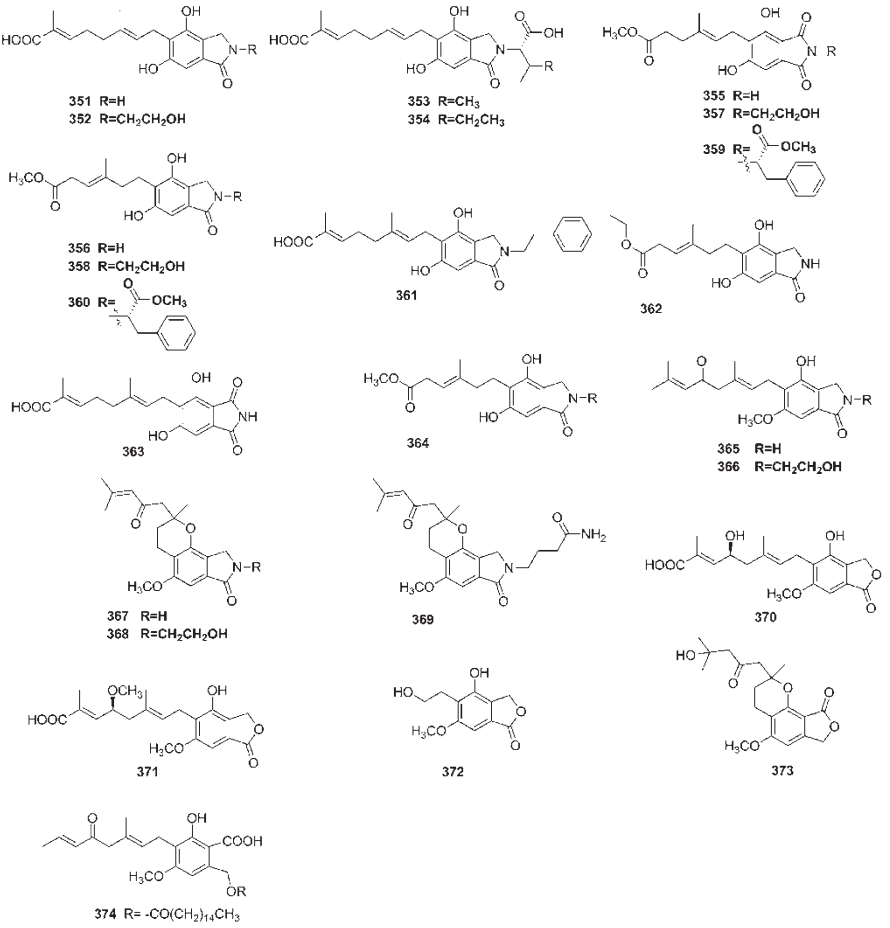
Two new macrocyclic meroterpenoids, ganocapensins A–B (**346–347**), together with three new aromatic meroterpenoids, ganomycins E–F (**348–349**) and fornicin E (**350**), were isolated from the fruiting bodies of *G. capense* (Peng et al. 2016). Compounds **346–350** exhibited antioxidant effects with IC_{50} values ranging from 6.00 ± 0.11 to 8.20 ± 0.30 μg/ml in the DPPH radical scavenging assay.



9.3.2 Polyketide-Terpenoids

9.3.2.1 *Hericium erinaceus*

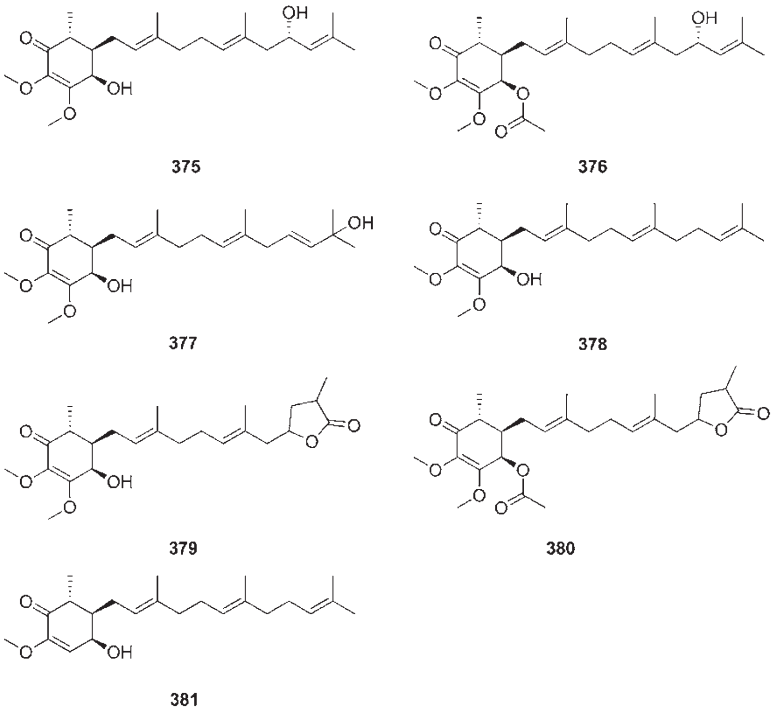
H. erinaceus is an important edible and medicinal mushroom. The fruiting bodies and mycelia of this mushroom have been used as an herbal medicine for the treatment of gastricism and hyperglycemia in China. The chemical constituents of *H. erinaceum* were widely investigated. Aromatic compounds and diterpenoids with various bioactivities have been isolated from *H. erinaceus*. Fourteen new meroterpenoids, erinacerins C–L (**351–360**) and erinacerins Q–T (**361–364**), were obtained from the mycelia of *H. erinaceus* fermented on rice (Wang et al. 2015c, d). Compounds **352–364** exhibited inhibitory activity against α-glucosidase with IC_{50} values ranging from 5.3 to 145.1 μM. Erinacerins Q–T (**361–364)** showed inhibitory activities against PTP1B. Erinaceolactams A–E (**365–369**), five new isoindolinones, were isolated from 70% ethanol extract of the fruiting bodies of *H. erinaceus* (Wang et al. 2016c). Five new meroterpenoid, erinaceolactones D–F (**370–372**), hericenone K (**373**), and hericenone L (**374**), were isolated from the fruiting bodies of *H. erinaceus* (Wang et al. 2016d; Zhang et al. 2015b; Ma et al. 2012). Hericenone L (**374**) exhibited cytotoxic activity against EC109 cell line with an IC_{50} of 46 μg·L^{-1}. Hericenone K (**373**) exhibited weak neurite outgrowth-promoting activity in NGF-induced PC12 cells.



9.3.2.2 *Antrodia camphorata*

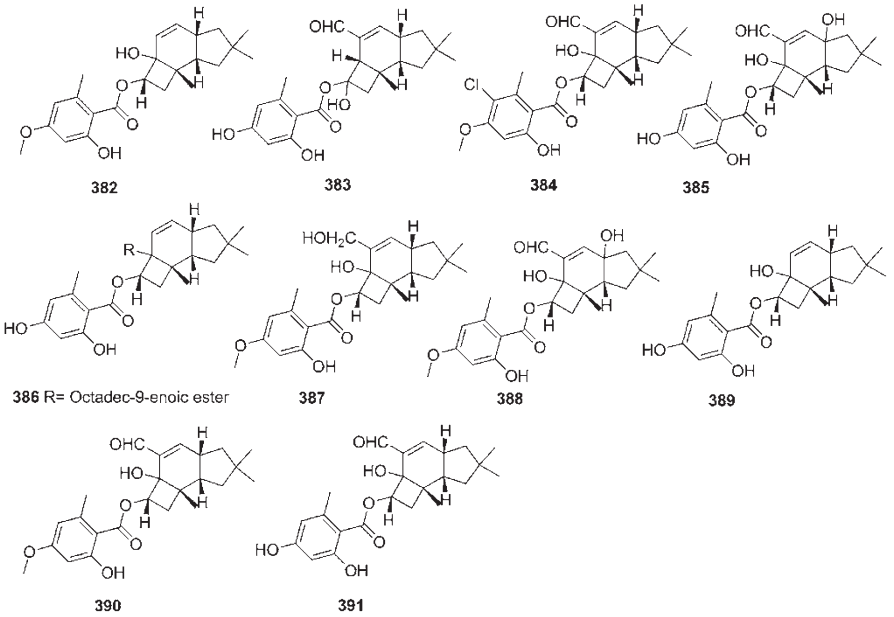
Four ubiquinone derivatives, antrocamol LT1 (**375**), antrocamol LT2 (**376**), antrocamol LT3 (**377**), and antroquinonol (**378**), were isolated from *A. camphorata* mycelium (Yen et al. 2015). Compounds **375**–**378** showed cytotoxicities against CT26, A549, HepG2, PC3, and DU-145 cell lines with IC_{50} values ranging from 0.01 to 1.79 μM. Antroquinonol B (**379**) and 4-acetyl-antroquinonol B (**380**) were obtained from the mycelium of *A. camphorata* (Yang et al. 2009). The two compounds were evaluated for their effects on the inhibition of NO production in LPS-activated murine macrophages. The bioassay displayed that compounds **379** and **380** possessed effects on NO inhibition, with IC_{50} values of 16.2 ± 0.8 and 14.7 ± 2.8 μg/mL, respectively. Moreover, antroquinonol D (**381**), a ubiquinone derivative, was isolated from the solid-state fermented mycelium of *A. camphorata*

(Wang et al. 2014b). Some research illuminated that antroquinonol D induces DNA demethylation and the recovery of multiple tumor suppressor genes while inhibiting breast cancer growth and migration potential.



9.3.2.3 *Armillaria mellea*

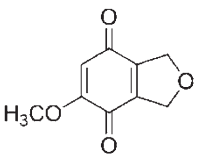
A. mellea is an important TCM used in dispelling the wind and removing an obstruction in the meridians and strengthening tendons and bones. Two new protoilludane sesquiterpene aryl esters, 5′-methoxy-armillasin (**382**) and 5-hydroxyl-armillarivin (**383**), as well as eight known protoilludane sesquiterpene aryl esters, armillaridin (**384**), armillartin (**385**), armillarin (**386**), melleolide B (**387**), armillarilin (**388**), armillasin (**389**), armillarigin (**390**), and melleolide (**391**), were isolated from the mycelium of *A. mellea* (Li et al. 2016b). Compounds **383–385** and **388–391** exhibited highly cytotoxic activity against HepG2 cells (4.95–37.65 μg/mL). Among all the ten compounds, melleolide (**391**) showed the best cytotoxic activity for HepG2 cells (4.95 μg/mL) and lower activity for L02 cells (16.05 μg/mL).



9.4 Polyketide

9.4.1 *Neolentinus lepideus*

N. lepideus is a basidiomycete mushroom of the genus *Neolentinus*, previously well known as *Lentinus lepideus*. It is one of the popular edible mushrooms in China, Japan, and Korea. Three new polyketides, 5-methoxyisobenzofuran-4,7(1H,3H)-dioneone (**392**), 1,3-dihydroisobenzofuran-4,6-diol (**393**), and benzoquinone derivative (**394**), were obtained from the solid culture of *N. lepideus* fermented on cooked rice (Li et al. 2013b). In the DPPH scavenging assay, compound **393** displayed antioxidant activity with IC_{50} of 68.6 μM. Compounds **392–394** showed potent inhibition of nitric oxide production in macrophages with an IC_{50} value of 6.2, 88.8, and 100 μM, respectively.



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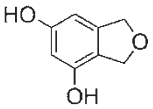

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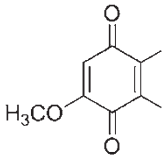

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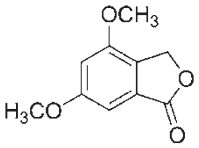

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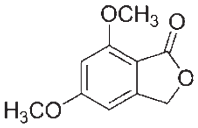

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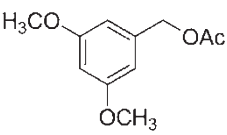

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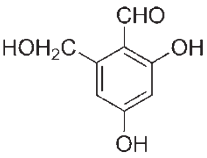

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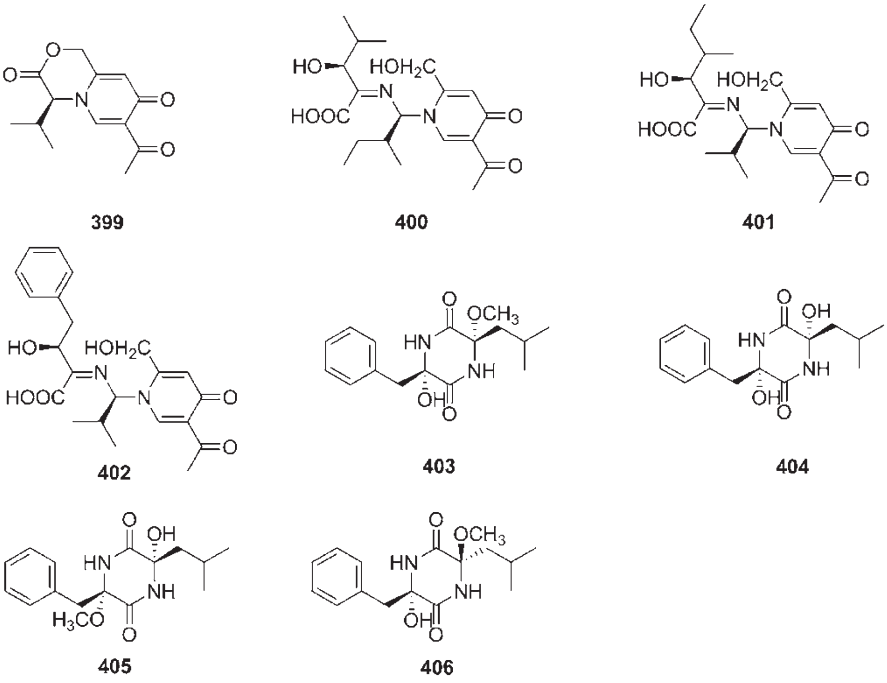
9.4.2 *Pleurotus* spp.

6-Dimethoxyisobenzofuran-1(3*H*)-one (**395**), a known polyketide, was isolated from the culture broth of the fungus *P. eryngii* (Liu et al. 2013). Three polyketides, 5, 7-dimethoxyisobenzofuran-1(3H)-one (**396**), 3, 5-dihydroxybenzyl acetate (**397**), and 2,4-dihydroxy-6-(hydroxymethyl) benzaldehyde (**398**), were isolated from the solid culture of *P. citrinopileatus* (Li et al. 2013c). Compounds **396–398** showed moderate chelating capacity with percent chelating value of 28.77%, 29.72%, and 39.47% at a concentration of 200 μmol/L, respectively. Compound **396** showed weak reducing ability with percent reducing the value of (22.22 ± 5.44) % at the concentration of 200 μmol/L.

9.5 Alkaloids and Other Nitrogen-Containing Compounds

9.5.1 *Hericium erinaceus*

Four new alkaloids, erinacerins M–P (**399–402**), were obtained from the mycelia of *H. erinaceus* fermented on rice (Wang et al. 2015d). Erinacerins M–P (**399–402**) showed moderate cytotoxicity against K562 cells with IC_{50} values of 16.3, 18.2, 15.9, and 11.4 μM, respectively, and also weak cytotoxicity against doxorubicin-resistant K562 cells.

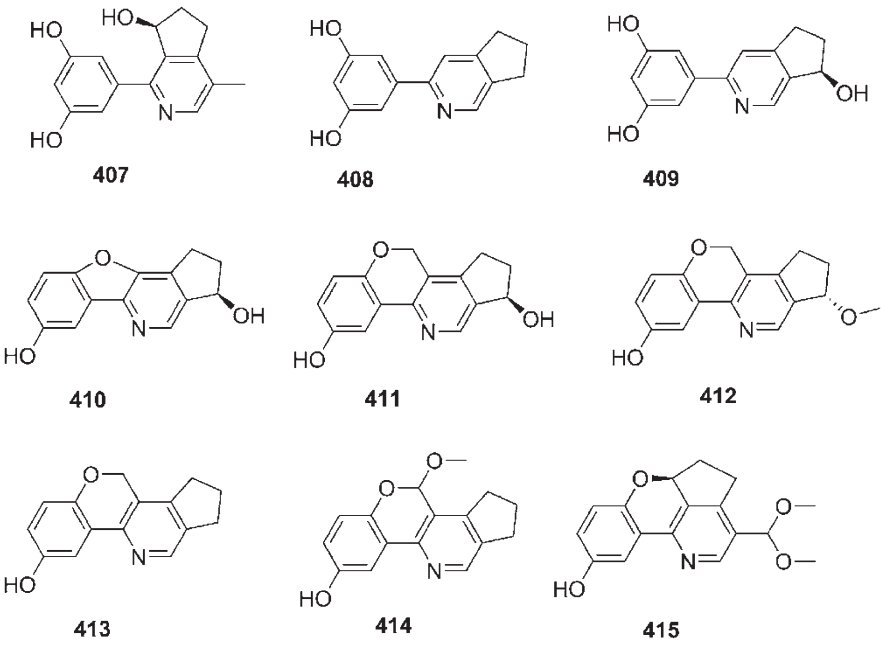


9.5.2 *Lepista sordida*

L. sordida, a basidiomycetous fungus of the family *Tricholomataceae*, is an edible agaric species. Three new 3,6-dioxygenated diketopiperazines, lepistamides A–C (**403–405**), along with a known compound, diatretol (**406**), were isolated from the mycelial solid cultures of the *L. sordida* (Chen et al. 2011). Compounds **403–406** were all found to be inactive (IC_{50} > 100 μg/ml) in the evaluation of the cytotoxic activity against Astc-a-1 (lung cancer), Bel-7402 (liver cancer), and HeLa (cervical carcinoma) cell lines by means of the MTT assay method.

9.5.3 *Ganoderma* spp.

Five new alkaloids, sinensines A–E (**407–411**), were isolated from the fruiting bodies of *G. sinense* (Liu et al. 2010, 2011). Sinensine A (**407**) exhibited activity in protecting the injury induced by hydrogen peroxide oxidation on human umbilical cord endothelial cells (HUVEC), with EC_{50} value of 6.2 mmol/L. Four new polycyclic alkaloids, lucidimines A–D (**412–415**), were isolated from the fruiting bodies of *G. lucidum* (Zhao et al. 2015).



9.6 Conclusion

In the past 10 years, substantial progress has been made by Chinese scientists in the field of bioactive metabolites from edible and medicinal fungi. Chemical investigations of the fruiting bodies and culture broth of the edible and medicinal fungi collected in China have resulted in 415 compounds including 90 sesquiterpenoids and 115 meroterpenoids belonging to shikimate-terpenoids. These compounds exhibit various bioactivities including antibacterial, antioxidant, anticancer, antiplasmodial, antiproliferative, antifibrotic, and neurite outgrowth-promoting activities. Edible and medicinal fungi produce enormously diverse metabolites, but only a small number has been explored. It is promising to search for leads of new drugs by continuing the further chemical investigations of edible and medicinal fungi.

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