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Review

Systematic Review of Chemical Constituents in the Genus *Lycium* (Solanaceae)

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Abstract: The *Lycium* genus is widely used as a traditional Chinese medicine and functional food. Many of the chemical constituents of the genus *Lycium* were reported previously. In this review, in addition to the polysaccharides, we have enumerated 355 chemical constituents and nutrients, including 22 glycerogalactolipids, 29 phenylpropanoids, 10 coumarins, 13 lignans, 32 flavonoids, 37 amides, 72 alkaloids, four anthraquinones, 32 organic acids, 39 terpenoids, 57 sterols, steroids, and their derivatives, five peptides and three other constituents. This comprehensive study could lay the foundation for further research on the *Lycium* genus.

Keywords: *Lycium* genus; chemical constituents; goji berry; Lycii cortex

1. Introduction

Lycium is one of the genera in the Solanaceae family, comprising 80 species, seven of which are found in China [1]. These species are all deciduous shrubbery, possessing a highly similar morphology and structure. The *Lycium* genus has been an important source of medicines and nutrient supplements for thousands of years in Southeast Asia, especially in China. Two species in particular, *Lycium barbarum* and *Lycium chinense*, have been widely used as traditional Chinese medicinal herbs for centuries and *L. barbarum* is currently widely cultivated in China.

Goji berries (Chinese name Gouqizi), which are derived from the fruits of *Lycium* Linn, have been used as traditional herbs for a long time in China for their benefits of replenishing vital essence to improve eyesight, nourish the liver and kidneys. Lycii cortex is a "heat cleansing" drug that is derived from the root bark of *L. chinense* and *L. barbarum* [2]. Goji berries and Cortex Lycii have demonstrated good therapeutic effects in some chronic diseases such as hectic fever, night sweats, cough, hemoptysis, and diabetes. Recently, medical research has indicated that these fruits and root bark have many pharmacological functions, such as antiglaucoma, immunoregulatory, antitumor, antioxidant, antiaging, neuroprotective, and blood sugar level reducing activities [3–10].

Traditionally, the berry and root bark available have been used as medicinal sources, as well as important components in some traditional Chinese patent medicines. They are not only famous medical herbs, but are also functional foods widely consumed in health-preserving cuisines, i.e., soups, congee, herbal tea, etc. People also eat the fresh leaves as vegetables. In particular, goji berries have become increasingly popular for improving overall well-being and as an anti-aging remedy. There are many goji derived-products on health food market, such as dried fruits, juice, goji wine and goji yoghurt. Many research papers were published focused on the phytochemical fingerprinting and antioxidant activity of these products [11–14].

Two valuable medicinal herbs, namely *L. barbarum* and *L. chinense*, have received remarkable attention due to their effective clinical therapy, especially in the anti-aging category. In addition, there are increasing numbers of publications about several other *Lycium* plants, i.e., *Lycium ruthenicum* [15,16]. Many researchers have focused great attention on the *Lycium* genus in recent years, and many chemical components from this genus have been isolated. Therefore, a comprehensive and systematic review on the chemical constituents of the *Lycium* genus is much needed.

Most of the published reviews not only covered chemical composition, but also summarized the pharmacology, clinical studies, safety, toxicology and adverse actions of *L. barbarum* or *L. chinense* [17–19]. The aim of this review was to focus on chemical constituents in different parts of plants from different species in *Lycium* genus, especially small molecular compounds with updated research reports. This paper comprehensively summarizes the reports of constituents from the genus *Lycium*. Up to 2016, at least 355 constituents were reported from different species in the *Lycium* genus and different parts (fruits, root bark, leaves, seeds, and flowers) of the plant. This review describes the advances in the phytochemistry of the genus *Lycium* from 1975 to 2016, based on the 142 cited references. The reported constituents can be classified as glycerogalactolipids, phenylpropanoids, coumarins, lignans, flavonoids, amides, alkaloids, anthraquinones, organic acids, terpenoids, sterols, steroids, peptides, and other constituents. The aim of this review is to illustrate the recent advances in the characterization of the *Lycium* genus. The results, based on these phytochemical studies, could lay a solid foundation for better understanding of pharmacological activities of *Lycium* and quality assessment.

2. Constituents

Until now, other than polysaccharides, more than 355 compounds have been isolated and identified from the *Lycium* genus. The small molecules can be assigned to various classes of glycerogalactolipids, phenylpropanoids, coumarins, lignans, flavonoids, amides, alkaloids, anthraquinones, organic acids, terpenoids, sterols, steroids and their derivatives, and peptides. Beyond that, other groups of compounds have also been reported. The proportion of different compounds of the *Lycium* genus is show in Figure 1. Their structures are shown below, and their names and corresponding plant sources are included in this paper.

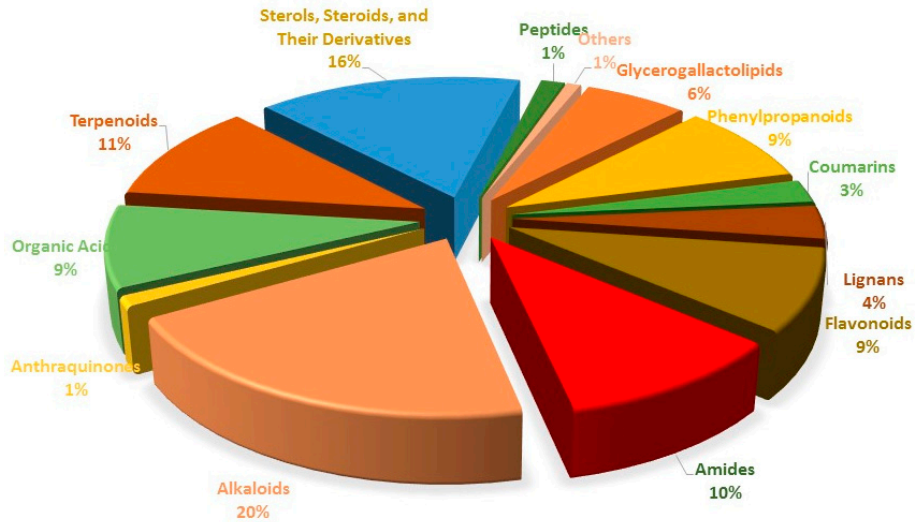


Figure 1. Different subtype comparison of the 355 constituents reported from *Lycium* genus.

2.1. Macromolecules in the Lycium Genus

Polysaccharides

Polysaccharides are the most important group of substances in the goji berry, which are estimated to comprise 5–8% of the dried fruits [20], 1.02–2.48% of the raw material [21–23]. More than 40 polysaccharides, with a molecular weight range of 8–241 kDa, were isolated from the fruit of *L. barbarum, L. chinense* and *L. ruthenicum.* Two, LRLP4-A and LBLP5-A, were isolated from the leaves of *L. ruthenicum*. The polysaccharides share a glycan-O-Ser glycopeptide structure and contain galacturonic acid, 18 amino acids, and nine monosaccharides, namely, xylose (Xyl), glucose (Glc), arabinose (Ara), rhamnose (Rha), mannose (Man), galactose (Gal), fucose (Fuc), galacturonic acid(GalA), glucuronic acid(GlcA) [24]. The molar ratios of the polysaccharides are shown in Table 1. The polysaccharides can be isolated and purified by water extract alcohol precipitation, DEAE ion-exchange cellulose, gel-permeation chromatography, high performance liquid chromatography (HPLC). Sevage method and organic reagents were used to remove proteins, pigments and other impurities. The structural composition of a LBP can be studied by SDS-PAGE gel electrophoresis, high perfomance size exclusion chromatography (HPSEC), gas-chromatographic–mass-spectrometry (GC-MS), nucleic magnetic resonance (NMR), and matrix-assisted laser desorption ionization-time of flight-mass spectrometry (MALDI-Tof-MS) [18,21,25].

Table 1. The molar ratios and source of LBPs.

LBPs	Molar Ratio	Source	Reference
LbGp1	Ara:Gal:Glc = 2.5:1.0:1.0	*L. barbarum*	[26]
LbGp2	Ara:Gal = 4:5	*L. barbarum*	[27]
LbGp3	Ara:Gal = 1:1	*L. barbarum*	[28,29]
LbGp4	Ara:Gal:Rha:Glc = 1.5:2.5:0.43:0.23	*L. barbarum*	[28,30]
LbGp5	Rha:Ara:Xyl:Gal:Man:Glc = 0.33:0.52:0.42:0.94:0.85:1	*L. barbarum*	[28]
LbGp5B	Rha:Ara:Glc:Gal = 0.1:1:1.2:0.3	*L. barbarum*	[31]
LBP3p	Rha:Ara:Xyl:Gal:Man:Glc = 1.25:1.10:1.76:1:1.95:2.12	*L. barbarum*	[32]
$LBPC_2$	Xyl:Rha:Man = 8.8:2.3:1	*L. barbarum*	[33]
$LBPC_4$	Glc	*L. barbarum*	[33]
LBPA1	heteroglycan	*L. barbarum*	[33]
LBPA3	heteroglycan	*L. barbarum*	[33]
LBP1a-1	Glc	*L. barbarum*	[34]
LBP1a-2	Glc	*L. barbarum*	[34]
LBP3a-1	GalA	*L. barbarum*	[34]
LBP3a-2	GalA	*L. barbarum*	[34]
LBPF1	-	*L. barbarum*	[35]
LBPF2	-	*L. barbarum*	[35]
LBPF3	-	*L. barbarum*	[35]
LBPF4	-	*L. barbarum*	[35]
LBPF5	Ara, Man, Xyl, Glu, Rha	*L. barbarum*	[35,36]
LBPF6	-	*L. barbarum*	[36]
LPBC4	Glc	*L. barbarum*	[37]
LBP-1	Rha:Ara:Xyl:Gal:Man:GalA = 1:7.85:0.37:0.65:3.01:8.16	*L. barbarum*	[22]
WSP1	Rha:Fuc:Ara:Xyl:Man:Gal:Glc = 1.6:0.2:51.4:4.8:1.2:25.9:7.3	*L. barbarum*	[23]
AGP	Rha:Ara:Xyl:Gal:Glc:GalA:GlcA = 3.3:42.9:0.3:44.3:2.4:7.0	*L. barbarum*	[38]
LBP-IV	Rha:Ara:Xyl:Glc:Gal = 1.61:3.82:3.44:7.54:1.00	*L. barbarum*	[39]
LbGp1	Ara:Gal = 5.6:1	*L. barbarum*	[40]
LBP-s-1	Rha:Ara:Xyl:Man:Glu:Gal:Gal A = 1.00:8.34:1.25:1.26:1.91:7.05:15.28	*L. barbarum*	[41]
p-LBP	Fuc:Rha:Ara:Gal:Glc:Xyl:Gal A:Glc A = 1.00:6.44:54.84:22.98:4.05:2.95:136.98:3.35	*L. barbarum*	[42]
Cp-2-A	Ara:Gal:Man:Rha:Glu = 6.02:2.71:1.00:0.70:0.67	*L. chinese*	[43,44]
Cp-2-B	Ara:Gal = 1:0.96	*L. chinese*	[43,44]
Hp-2-A	Ara:Gal = 5.2:1	*L. chinese*	[43,44]

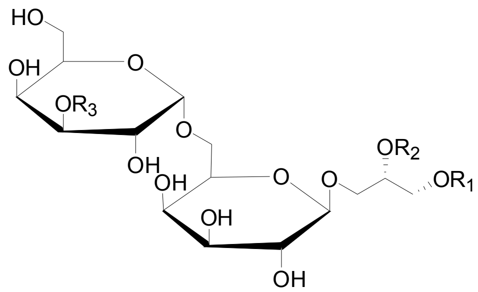
Hp-2-B	Ara:Gal = 7.9:1	*L. chinese*	[43,44]
Hp-2-C	Ara:Gal = 1.2:1	*L. chinese*	[43,44]
Hp-0-A	Ara:Gal = 14:1	*L. chinese*	[43,44]
Cp-1-A	Ara:Xyl = 1:1	*L. chinese*	[45]
Cp-1-B	Ara	*L. chinese*	[45]
Cp-1-C	Ara:Gal = 3:1	*L. chinese*	[45]
Cp-1-D	Ara:Gal = 1:1	*L. chinese*	[45]
LRGP1	Rha:Ara:Xyl:Man:Glu:Gal = 0.65:10.71:0.33:0.67:1:10.41	*L. ruthenicum*	[46]
LRGP2	-	*L. ruthenicum*	[47]
LRGP3	Rha:Ara:Gal = 1.0:14.9:10.4	*L. ruthenicum*	[48]
LRGP4-A	Rha:Ara:Glu:Gal = 1:7.6:0.5:8.6	*L. ruthenicum*	[49]
LRGP5	Rha:Ara:Xyl:Gal:GalA = 1.0:2.2:0.5:1.2:4.7	*L. ruthenicum*	[50]
LRLP4-A	Rha:Ara:Gal = 1:10.3:5.3	*L. ruthenicum*	[47]
LBLP5-A	-	*L. ruthenicum*	[51]

2.2. Small Molecule Substances

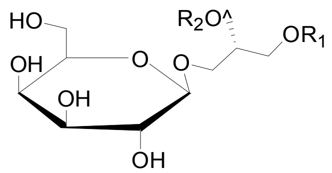
2.2.1. Glycerogalactolipids **1–22**

At present, 17 compounds of this type, a series of glycerogalactolipids **1–17**, listed in Table 2, have been isolated and identified. Compounds **1–15** have been isolated and identified from the fruits of *L. barbarum* [52], whereas **16** and **17** were isolated from the fruits of *L. chinense* [53]. Compounds **18–22**, illustrated in Figure 2, were isolated from the root bark of *L. chinense* [54,55].

Table 2. Chemical structures of compounds **1–17**.

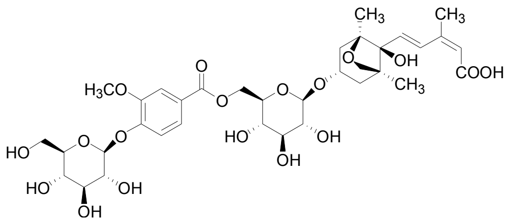


1–12

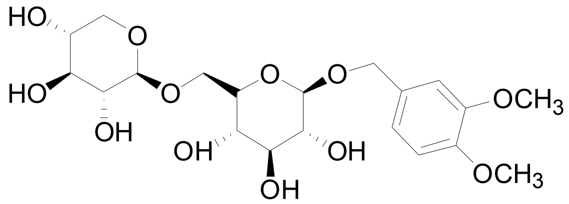


13–17

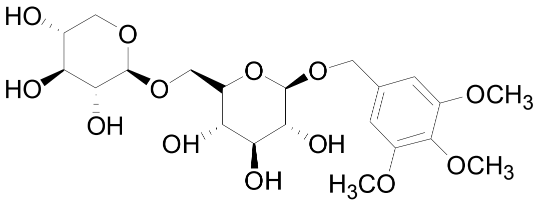
No.	Compounds	R_1	R_2	R_3	Source
1	Glycerogalactolipids A	Palmitoyl	Linolenoyl	Linolenoyl	*L. barbarum*
2	Glycerogalactolipids B	Palmitoyl	Linolenoyl	Linoleoyl	*L. barbarum*
3	Glycerogalactolipids C	Palmitoyl	Linolenoyl	Palmitoyl	*L. barbarum*
4	Glycerogalactolipids D	Palmitoyl	Linoleoyl	Palmitoyl	*L. barbarum*
5	Glycerogalactolipids E	Palmitoyl	Palmitoyl	Palmitoyl	*L. barbarum*
6	Glycerogalactolipids F	Palmitoyl	Palmitoyl	H	*L. barbarum*
7	Glycerogalactolipids G	Linolenoyl	Linolenoyl	H	*L. barbarum*
8	Glycerogalactolipids H	Linolenoyl	Linoleoyl	H	*L. barbarum*
9	Glycerogalactolipids I	Palmitoyl	Linolenoyl	H	*L. barbarum*
10	Glycerogalactolipids J	Palmitoyl	Linoleoyl	H	*L. barbarum*
11	Glycerogalactolipids K	Palmitoyl	Oleoyl	H	*L. barbarum*
12	Glycerogalactolipids L	Stearoyl	Linoleoyl	H	*L. barbarum*
13	Glycerogalactolipids M	Palmitoyl	Linolenoyl	–	*L. barbarum*
14	Glycerogalactolipids N	Palmitoyl	Linoleoyl	–	*L. barbarum*
15	Glycerogalactolipids O	Palmitoyl	Oleoyl	–	*L. barbarum*
16	Glycerogalactolipids P	Linolenoyl	Linolenoyl	–	*L. chinense*
17	Glycerogalactolipids Q	Linoleoyl	Linolenoyl	–	*L. chinense*



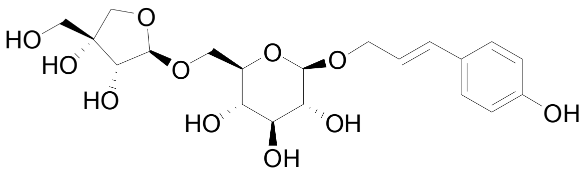
18 Lyciumoside A



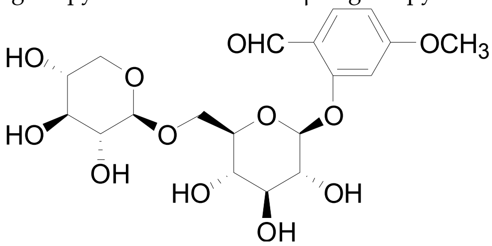
19 3′,4′-Dimethoxy-benzylalcohol-l-*O*-β-D-xylopyranosyl-(1 → 6)-*O*-β-D-glucopyranoside



20 3′,4′,5′-Trimethoxy-benzylalcohol-l-*O*-β-D-xylopyranosyl-(1 → 6)-*O*-β-D-glucopyranoside



21 4′-Hydroxystyrone-l-*O*-β-D-apiofuranosyl-(1 → 6)-*O*-β-D-glucopyranoside



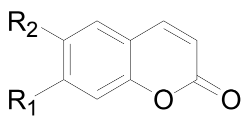
22 2-Hydroxy-4-methoxybenzaldehyde-2-*O*-β-D-glucopyraneosyl-l-6-*O*-β-D-xylopyranoside

Figure 2. Chemical structures of compounds **18**–**22**.

2.2.2. Phenylpropanoids 23–51

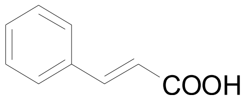
Four phenylpropanoids **23**–**26**, namely *E*-cinnamic acid (**23**), *E*-ferulic acid (**24**), *E*-coniferol (**25**) and isoscopoletin (**26**) are obtained from wolfberries [56–58]. Four phenylpropanoids, namely scopolin (**27**), fabiatrin (**28**), lyciumin (**29**), and 9-*O*-(β-D-glucopyranosyl)lyoniresinol (**30**) are obtained from the root bark of *L. chinense* [59–61]. 1-*O*-Methyl-4-*O*-*p*-*E*-coumaroyl-α-L-rhamnopyranoside (**31**) is obtained from the fruits of *L. ruthenicum* [62]. The chemical structures of compounds **23**–**33** are listed in Table 3 and Figure 3. In 2016, 11 phenylpropanoids **32**–**42** were isolated for the first time by Zhou et al. from *Lycium* [56], including 1-*O*-*E*-feruloyl-6-*O*-β-D-xylopyranosyl-β-D-glucopyranoside (**32**), 6-*O*-*E*-feruloyl-2-*O*-β-D-glucopyranosyl-α-D-glucopyranoside (**33**), 1-*O*-*E*-feruloyl-β-D-glucopyranoside (**34**), ethyl-4-*O*-β-D-glucopyranosyl-*E*-ferulate (**35**), ethyl *E*-ferulate (**36**), *E*-sinapinic acid (**37**), syringenin (**38**), *Z*-ferulic acid (**39**), phloretic acid (**40**), dihydroferulic acid (**41**), and ethyl dihydroferulate (**42**), along with the nine new lycibarbarphenylpropanoids A–I (compounds **43**–**51**) listed in Table 4.

Table 3. Chemical structures of compounds **26**–**28**.

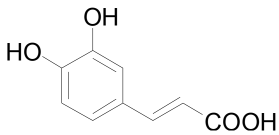


26–28

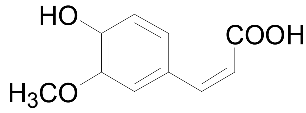
No.	Compounds	R_1(R)	R_2	Source
26	Isoscopoletin	OCH_3	OH	*L. barbarum*
27	Scopolin	*O*-β-D-Glc	OCH_3	*L. chinense*
28	Fabiatrin	*O*-β-D-Glc^6-β-D-Xyl	OCH_3	*L. chinense*



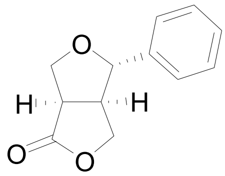
23 *E*-cinnamic acid



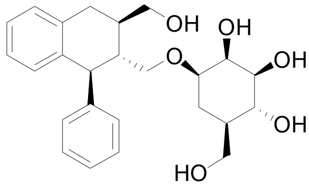
24 *E*-ferulic acid



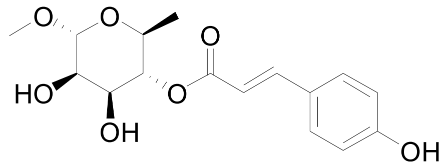
25 *Z*-coniferol



29 Lyciumin



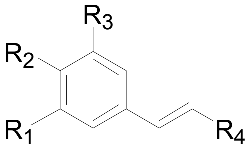
30 9-*O*-(β-D-glucopyranosyl)-lyoniresinol



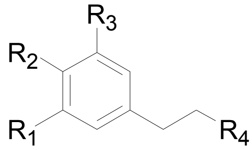
31 1-*O*-methyl-4-*O*-*p*-*E*-coumaroyl-α-L-rhamnopyranoside

Figure 3. Chemical structures of compounds **23–25**, **29–31**.

Table 4. Chemical structures of compounds **32–51**.



32–39, 43–51

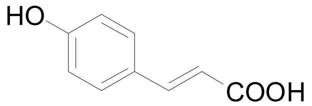


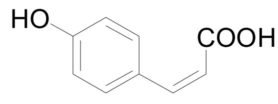
40–42

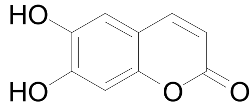
No.	Compounds	R_1	R_2	R_3	R_4	Source
32	1-*O*-*E*-feruloyl-6-*O*-β-D-xylopyranosyl-β-D-glucopyranoside	OCH_3	OH	H	COO-β-D-Glc^6-β-D-Xyl	*L. barbarum*
33	6-*O*-*E*-feruloyl-2-*O*-β-D-glucopyranosyl-α-D-glucopyranoside	OCH_3	OH	H	COO^6-α-D-Glc^2-β-D-Glc	*L. barbarum*
34	1-*O*-*E*-feruloyl-β-D-glucopyranoside	OCH_3	OH	H	COO-β-D-Glc	*L. barbarum*
35	Ethyl-4-*O*-β-D-glucopyranosyl-*E*-ferulate	OCH_3	*O*-β-D-Glc	H	$COOCH_2CH_3$	*L. barbarum*
36	Ethyl *E*-ferulate	OCH_3	OH	H	$COOCH_2CH_3$	*L. barbarum*
37	*E*-sinapinic acid	OCH_3	OH	OCH_3	COOH	*L. barbarum*
38	Syringenin	OCH_3	OH	OCH_3	CH_2OH	*L. barbarum*
39	*E*-ferulic acid	OCH_3	OH	H	COOH	*L. barbarum*
40	Phloretic acid	H	OH	H	COOH	*L. barbarum*
41	Dihydroferulic acid	OCH_3	OH	H	COOH	*L. barbarum*
42	Ethyl dihydroferulate	OCH_3	OH	H	$COOCH_2CH_3$	*L. barbarum*
43	Lycibarbarphenylpropanoids A	H	OH	H	COO-β-D-Glc^3-β-D-Glc	*L. barbarum*
44	Lycibarbarphenylpropanoids B	H	OH	H	COO-β-D-Glc^4-β-D-Glc	*L. barbarum*
45	Lycibarbarphenylpropanoids C	OCH_3	OH	H	COO-β-D-Glc^3-β-D-Glc	*L. barbarum*
46	Lycibarbarphenylpropanoids D	OCH_3	OH	H	COO-β-D-Glc^4-β-D-Glc	*L. barbarum*
47	Lycibarbarphenylpropanoids E	OCH_3	OH	H	CH_2O-β-D-Glc^3-β-D-Glc	*L. barbarum*
48	Lycibarbarphenylpropanoids F	H	*O*-β-D-Glc^3-β-D-Glc	H	$COOCH_2CH_3$	*L. barbarum*
49	Lycibarbarphenylpropanoids G	H	*O*-β-D-Glc^4-β-D-Glc	H	$COOCH_2CH_3$	*L. barbarum*
50	Lycibarbarphenylpropanoids H	OCH_3	*O*-β-D-Glc^4-β-D-Glc	H	$COOCH_2CH_3$	*L. barbarum*
51	Lycibarbarphenylpropanoids I	*O*-β-D-Glc	OH	H	$COOCH_2CH_3$	*L. barbarum*

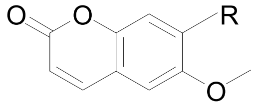
2.2.3. Coumarins **52–61**

Nine coumarins, namely *E*-*p*-coumaric acid (**52**), *Z*-*p*-coumaric acid (**53**), esculetin (**54**), fabiatrin (**55**), scopolin (**56**), and scopoletin (**57**), have been reported, and three new coumarins, 6-*O*-*E*-*p*-coumaroyl-2-*O*-β-D-glucopyranosyl-α-D-glucopyranoside (**58**), ethyl-4-*O*-β-d-glucopyranosyl-*E*-*p*-coumarate (**59**), ethyl *E*-*p*-coumarate (**60**) and lycibarbarcoumarin A (**61**), have been obtained from the fruits of *L. barbarum* in 2016 [56]. Compounds **55** and **56** were isolated from the root bark and fruits of *L. chinense* [61], while **52**–**54** and **57** were isolated from the fruits of *L. barbarum* [63]. The chemical structures of these coumarins are listed in Figure 4 and Table 5.


52 *E*-*p*-coumaric acid


53 *Z*-*p*-coumaric acid

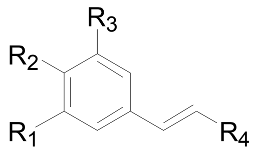

54 esculetin



55	Fabiatrin	R=*O*-β-D-Glc⁶-β-D-Xyl
56	Scopolin	R=*O*-β-D-Glc
57	Scopoletin	R=OH
61	Lycibarbarcoumarin A	R=*O*-β-D-Glc⁶-β-D-Xyl⁴-β-D-Glc

Figure 4. Chemical structures of compounds **52**–**57**, **61**.

Table 5. Chemical structures of compounds **58**–**60**.

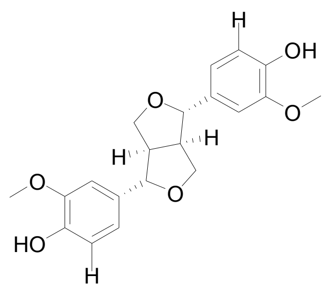

59–61

No.	Compounds	R_1	R_2	R_3	R_4	Source
58	6-*O*-*E*-*p*-coumaroyl-2-*O*-β-D-glucopyranosyl-α-D-glucopyranoside	H	OH	H	COO⁶-α-D-Glc²-β-D-Glc	*L. barbarum*
59	Ethyl-4-*O*-β-D-glucopyranosyl-*E*-*p*-coumarate	H	*O*-β-D-Glc	H	$COOCH_2CH_3$	*L. barbarum*
60	Ethyl *E*-*p*-coumarate	H	OH	H	$COOCH_2CH_3$	*L. barbarum*

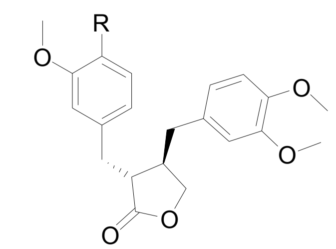
2.2.4. Lignans **62**–**74**

Eight lignans, including pinoresinol (**62**), arctigenin (**63**), arctiin (**64**), medioresinol (**65**), syringaresinol (**66**), 4-*O*-(β-D-glucopyranosyl)syringaresinol (**67**), *threo*-1,2-bis(4-hydroxy-3-methoxyphenyl)-1,3-propanediol (**68**), and *erythro*-1,2-bis(4-hydroxy-3-methoxyphenyl)-1,3-propanediol (**69**), have been isolated from the fruits of *L. barbarum* [56]. (β)-Lyoniresinol 3-*O*-β-D-glucopyranoside (**70**), lyciumlignan A (**71**), lyciumlignan B (**72**), lyciumlignan C (**73**), and (7*R*,8*S*)-4,9,9′-trihydroxy-3,3′-dimethoxy-7′-en-8,4′-oxyneolignan-7-*O*-β-D-glucopyranoside (**74**) were obtained from the root bark of *L. chinense* [54,60,64]. Among them, **65**–**70** were first isolated from the fruits of *L. barbarum* in 2016 [56]. The chemical structures of these lignans are listed in Figure 5 and Table 6.

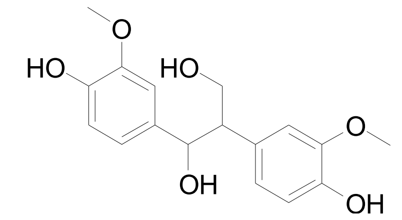
Table 6. Chemical structures of compounds **62** and **65**–**67**.


62, **65**–**67**

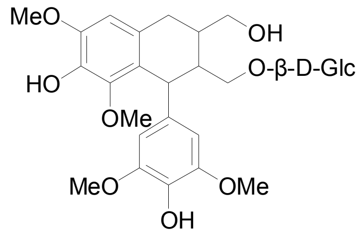
No.	Compounds	R_1	R_2	R_3	Source
62	Pinoresinol	H	OH	H	*L. barbarum*
65	Medioresinol	H	OH	OCH_3	*L. barbarum*
66	Syringaresinol	OCH_3	OH	OCH_3	*L. barbarum*
67	4-*O*-(β-D-glucopyranosyl)syringaresinol	OCH_3	*O*-β-D-Glc	OCH_3	*L. barbarum*



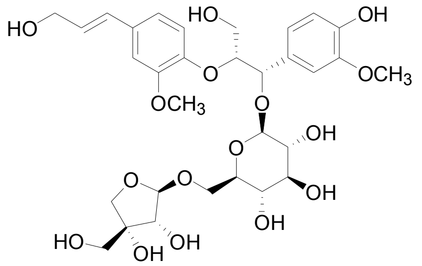
63 Arctigenin R=OH
64 Arctiin R=*O*-β-D-Glc



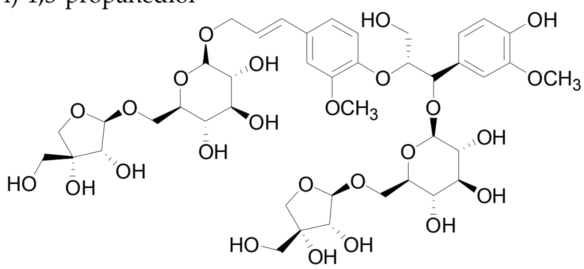
68 *threo*-1,2-bis(4-Hydroxy-3-methoxyphenyl)-1,3-propanediol
69 *erythro*-1,2-bis(4-Hydroxy-3-methoxyphenyl)-1,3-propanediol



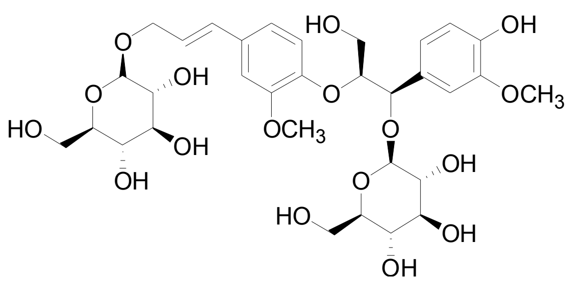
70 (β)-Lyoniresinol 3-*O*-β-D-glucopyranoside



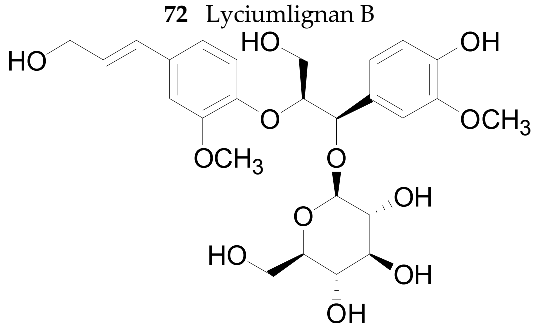
71 Lyciumlignan A



72 Lyciumlignan B



73 Lyciumlignan C



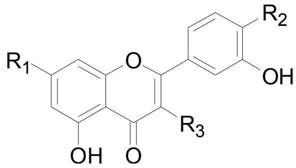
74 (7*R*,8*S*)-4,9,9′-Trihydroxy-3,3′-dimethoxy-7′-en-8,4′-oxyneolignan-7-*O*-β-D-glucopyranoside

Figure 5. Chemical structures of compounds **63**–**64** and **68**–**74**.

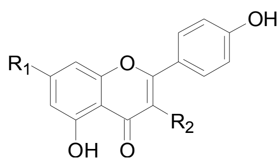
2.2.5. Flavonoids 75–106

Twenty-seven flavonoids **75**–**101** have been reported from the genus *Lycium*, are listed in Tables 7 and 8 and Figures 6 and 7. Compound **75** was isolated from the flowers of *L. barbarum* [58], while **76**–**83** were identified from the fruits of *L. barbarum* [62,65–69]. Compound **84** was isolated from the fruits of *L. chinense* [70], whereas **85**–**91** were isolated from the leaves of *L. chinense* [62,66,68,71]. Compound **92** and **93** were isolated from the leaves of *L. halimifolium* [72]. Compounds **94**–**98** were isolated from the fruits of *L. ruthenicum* [16,62]. Compounds **99**–**101** were isolated from the root bark of *L. chinense* [54,73,74]. Additionally, Zhou et al. isolated five isoflavonoids, namely derrone (**102**), alpinumisoflavone (**103**), auriculasin (**104**), maackianin (**105**) and maackiain (**106**) from the fruits of *L. barbarum* [56,75,76].

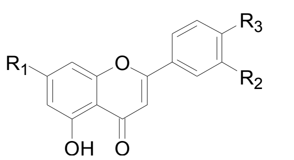
Table 7. Chemical structures of compounds **75**–**80**, **82**–**83**, **85**–**87** and **89**–**93**.



75,77–80,87,90,92



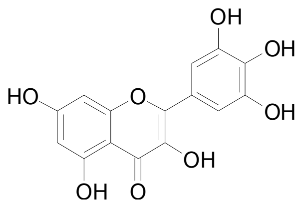
7,82–83,93



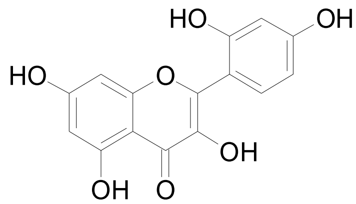
85–86,89,91

No.	Compounds	R_1	R_2	R_3	Source
75	Quercitrin	OH	OH	O-α-L-Rha	*L. barbarum*
76	Kaempferol	OH	OH	–	*L. barbarum*
77	Quercetin	OH	OH	OH	*L. barbarum*
78	Rutin	OH	OH	*O*-β-D-Glc^6-α-L-Rha	*L. barbarum*
79	Narcissoside	OH	OCH_3	*O*-β-D-Glc^6-α-L-Rha	*L. barbarum*

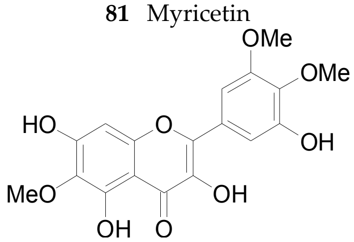
80	7-*O*-(β-D-Glucopyranosyl)-rutin	*O*-β-D-Glc	OH	*O*-β-D-Glc^{6}-α-L-Rha	*L. barbarum*
82	7-*O*-(β-D-Glucopyranosyl)-nicotiflorin	*O*-β-D-Glc	*O*-β-D-Glc^{6}-α-L-Rha	–	*L. barbarum*
83	7-*O*-(β-D-Glucopyranosyl)-3-*O*-[β-D-glucopyranosyl]-(1 → 2)-β-D-galactop	*O*-β-D-Glc	*O*-β-D-Glc^{6}-α-L-Glc	–	*L. barbarum*
85	Luteolin	OH	OH	OH	*L. chinense*
86	Acacetin	OH	H	OCH_3	*L. chinense*
87	7-*O*-(β-D-Glucopyranosyl)-3-*O*-[β-D-glucopyranosyl-(1 → 2)-β-D-galactopyranosyl]-quercetin	*O*-β-D-Glc	OH	*O*-β-D-Glc^{2}-β-D-Glc	*L. chinense*
89	7-*O*-[α-L-Rhamno-pyranosyl-(1 → 6)-β-D-glucopyranosyl]-acacetin	*O*-β-D-Glc^{6}-α-L-Rha	H	OCH_3	*L. chinense*
90	3-*O*-Sophoroside-quercetin	OH	OH	*O*-β-D-Glc^{2}-β-D-Glc	*L. chinense*
91	Apigenin	OH	H	OH	*L. chinense*
92	Isoquercitrin	OH	OH	*O*-β-D-Glc	*L. halimifolium*
93	Nicotiflorin	OH	*O*-β-D-Glc^{6}-α-L-Rha	–	*L. halimifolium*



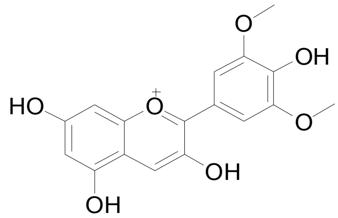
81 Myricetin



84 Morin



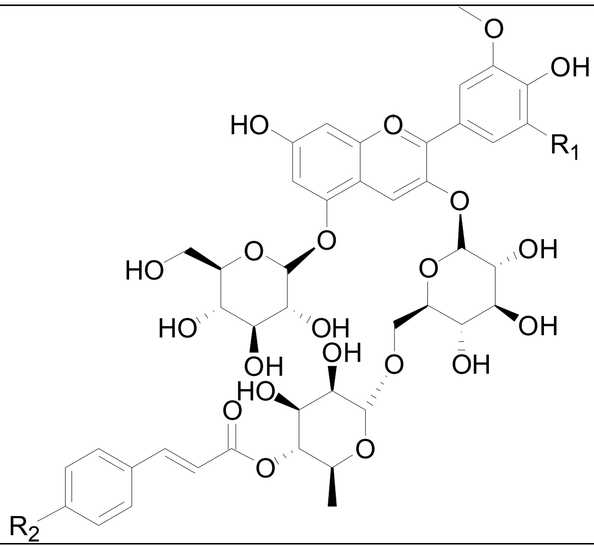
88 3,5,7,3′-Tetrahydroxy-6,4′,5′trimethoxyflavone



94 Malvidin

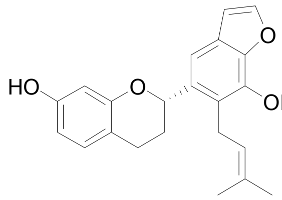
Figure 6. Chemical structures of compounds **81**, **84**, **88** and **94**.

Table 8. Chemical structures of compounds **95**–**98**.

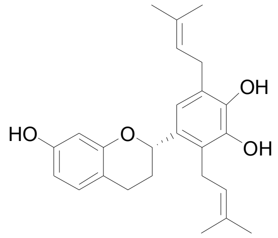


No.	Compounds	R_1	R_2	Source
95	5-*O*-(β-D-Glucopyranosyl)-3-*O*-[4-*O*-*p*-*E*-coumaroyl-α-L-rhamnopyranosyl-(1 → 6)-β-D-glucopyranosyl]-peonidin	H	OH	*L. ruthenicum*
96	5-*O*-(β-D-Glucopyranosyl)-3-*O*-[4-*O*-*p*-*E*-coumaroyl-α-L-rhamnopyranosyl-(1 → 6)-β-D-glucopyranosyl]-petunidin	OH	OH	*L. ruthenicum*

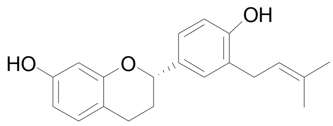
97	5-*O*-(β-D-Glucopyranosyl)-3-*O*-[4-*O*-*p*-*Z*-coumaroyl-α-L-rhamnopyranosyl-(1 → 6)-β-D-glucopyranosyl]-malvidin	OCH_3	OH	*L. ruthenicum*
98	5-*O*-(β-D-Glucopyranosyl)-3-*O*-[4-*O*-*p*-*E*-(β-D-glucopyranoside)-coumaroyl-α-L-rhamnopyranosyl-(1 → 6)-β-D-glucopyranosyl]-petunidin	OH	*O*-β-D-Glc	*L. ruthenicum*



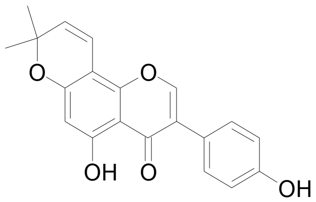
99 Lyciumflavane A



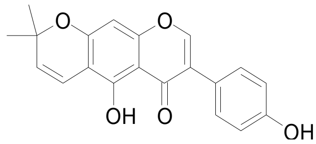
100 Kcazinol A



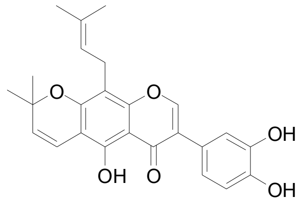
101 ,4′-Dihydroxy-5′-isopentene flavane



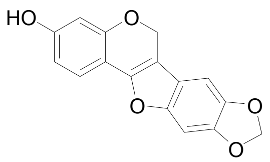
102 Derrone



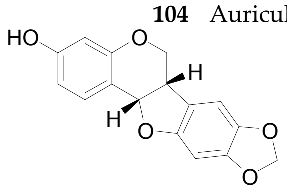
103 Alpinumisoflavone



104 Auriculasin



105 Maackianin

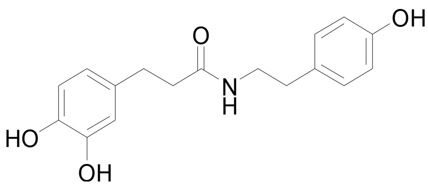


106 Maackiain

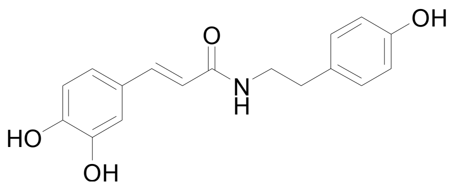
Figure 7. Chemical structures of compounds **99–106**.

2.2.6. Amides **107–143**

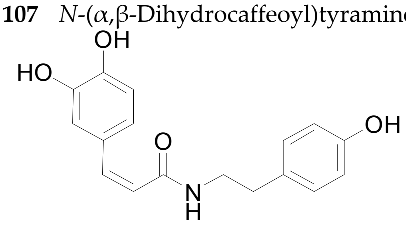
Sixteen amides **107–122** have been isolated from the root bark of *L. chinense* [9,54,60,77–80], 19 amides (**123–141**) have been isolated from the fruits of *L. barbarum* [81–88]. Meanwhile, two cerebrosides **142** and **143** have been obtained from fruits of *L. chinense* [89]. The chemical structures of these amides are shown in Figure 8.



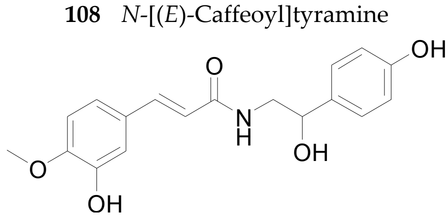
107 *N*-(α,β-Dihydrocaffeoyl)tyramine



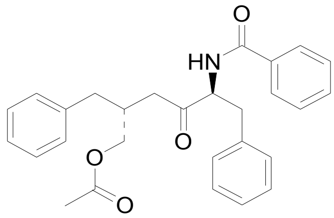
108 *N*-[(*E*)-Caffeoyl]tyramine



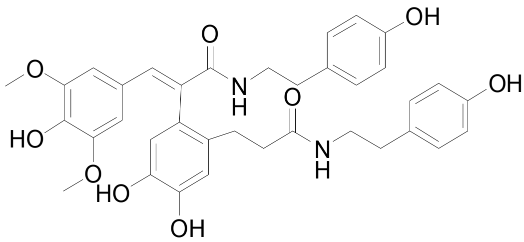
109 *N*-[(*Z*)-Caffeoyl]tyramine



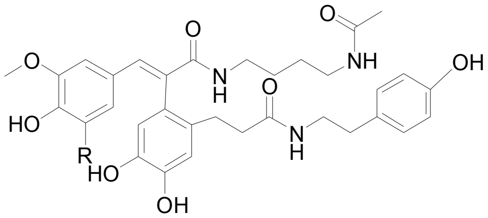
110 *N*-[(*E*)-Feruloyl]octopamine



111 Aurantiamide acetate

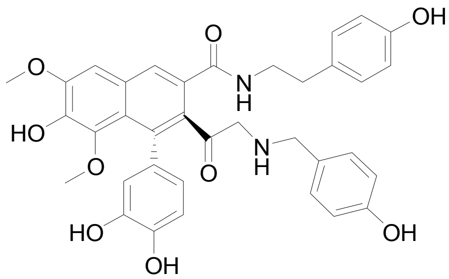


112 (*E*)-2-[4,5-Dihydroxy-2-[3-[2-(4-hydroxyphenyl) ethylamino]-3-oxopropyl]phenyl]-3-(4-hydroxy-3,5-dimethoxyphenyl)-*N*-[2-(4-hydroxyphenyl) ethyl]prop-2-enamide

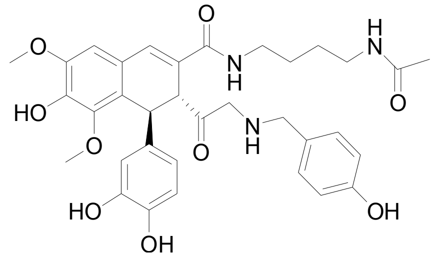


113 (*E*)-*N*-(4-Acetamidobutyl)-2-[4,5-dihydroxy-2-[3-[2-(4-hydroxyphenyl)ethylamino]-3-oxopropyl]-phenyl]-3-(4-hydroxy-3-methoxyphenyl)prop-2-enamide R=H

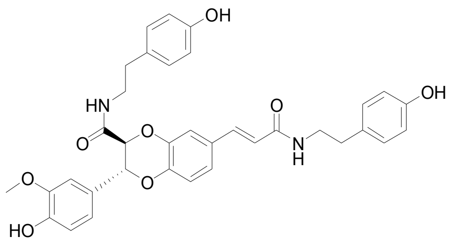
114 (*E*)-*N*-(4-Acetamidobutyl)-2-[4,5-dihydroxy-2-[3-[2-(4-hydroxyphenyl)ethylamino]-3-oxopropyl]-phenyl]-3-(4-hydroxy-3,5-dimethoxyphenyl)prop-2-enamide R=OCH_3



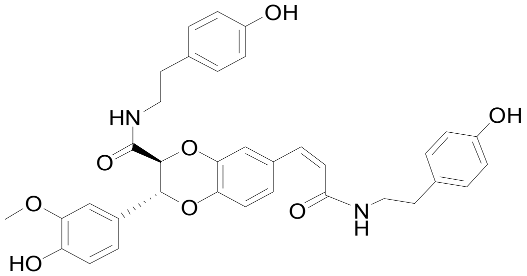
115 (1*R*,2*S*)-1-(3,4-Dihydroxyphenyl)-7-hydroxy-*N*2,*N*3-bis(4-hydroxyphenethyl)-6,8-dimethoxy-1,2-dihydro-naphthalene-2,3-dicarboxamide



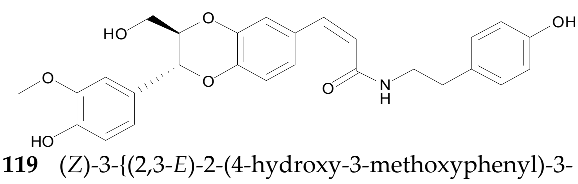
116 (1*S*,2*R*)-*N*3-(4-Acetamidobutyl)-1-(3,4-dihydroxy-phenyl)-7-hydroxy-*N*2-(4-hydroxyphenethyl)-6,8-dimethoxy-1,2-dihydro-naphthalene-2,3-dicarboxamide



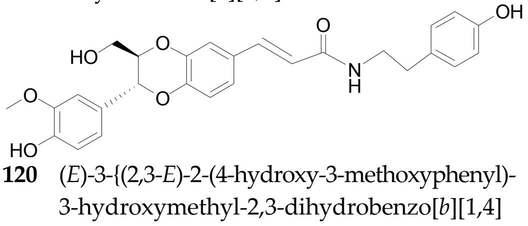
117 (2,3-*E*)-3-(3-Hydroxy-5-methoxyphenyl)-*N*-(4-hydroxyphenethyl)-7-{(*E*)-3-[(4-hydroxyphenethyl)-=amino]-3-oxoprop-1-en-1-yl}-2,3-dihydrobenzo-[*b*][1,4]dioxine-2-carboxamide



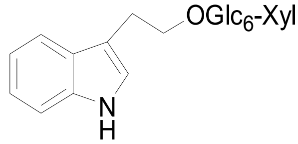
118 (2,3-*E*)-3-(3-hydroxy-5-methoxyphenyl)-*N*-(4-hydroxyphenethyl)-7-{(*Z*)-3-[(4-hydroxy-phenethyl)amino]-3-oxoprop-1-en-1-yl}-2,3-dihydrobenzo[*b*][1,4]dioxine-2-carboxamide



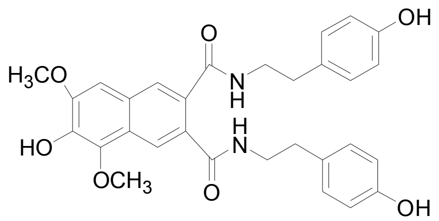
119 (*Z*)-3-{(2,3-*E*)-2-(4-hydroxy-3-methoxyphenyl)-3-hydroxymethyl-2,3-dihydrobenzo[*b*][1,4]dioxin-6-yl}-*N*-(4-hydroxyphenethyl)acrylamide



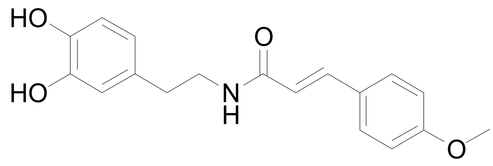
120 (*E*)-3-{(2,3-*E*)-2-(4-hydroxy-3-methoxyphenyl)-3-hydroxymethyl-2,3-dihydrobenzo[*b*][1,4] dioxin-6-yl}-*N*-(4-hydroxyphenethyl)-acrylamide



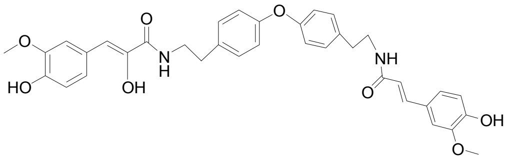
121 Indole glycoside



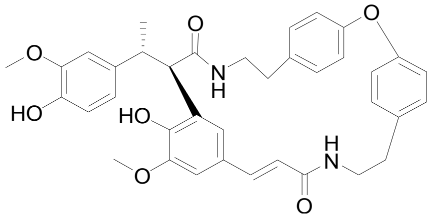
122 Lyciumamide D



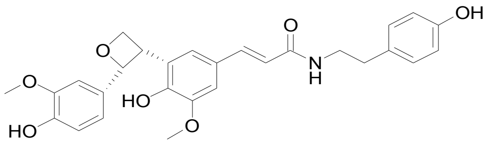
123 Lyciumide A



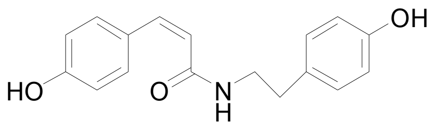
124 Lyciumamide A



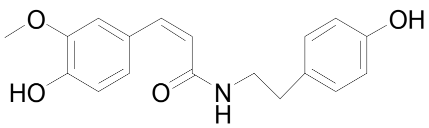
125 Lyciumamide B



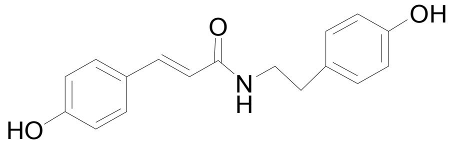
126 Lyciumamide C



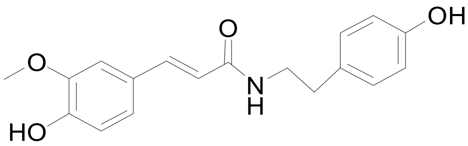
127 *N*-*Z*-*p*-coumaroyl-tyramine



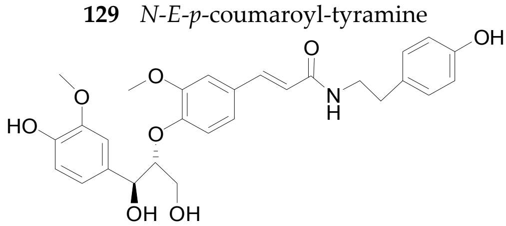
128 *N*-*Z*-feruloyl-tyramine



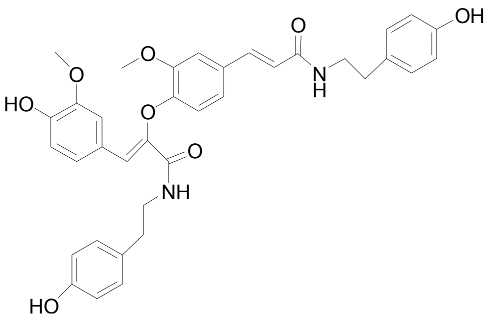
129 *N*-*E*-*p*-coumaroyl-tyramine



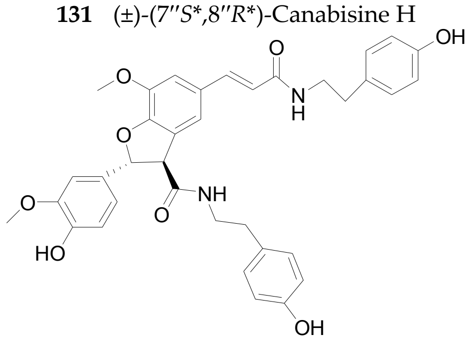
130 *N*-*E*-feruloyl-tyramine



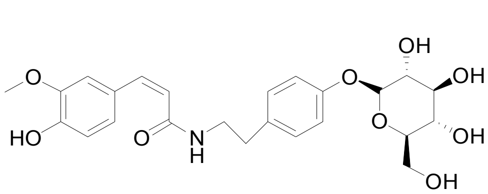
131 (±)-(7′′*S**,8′′*R**)-Canabisine H



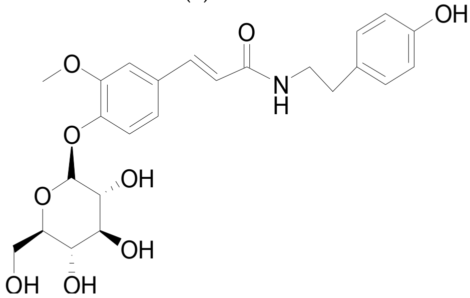
132 Cannabisin F



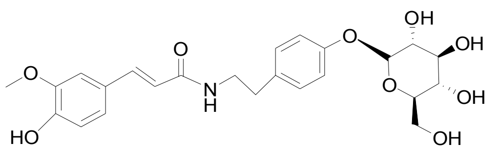
133 (±)-Grossamide



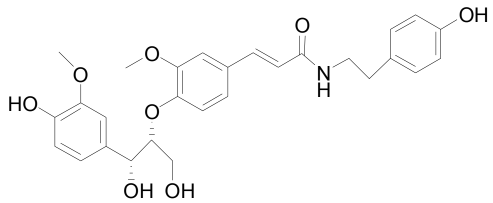
134 *N*-*Z*-feruloyl-4-*O*-(β-D-glucopyranosyl) tyramine



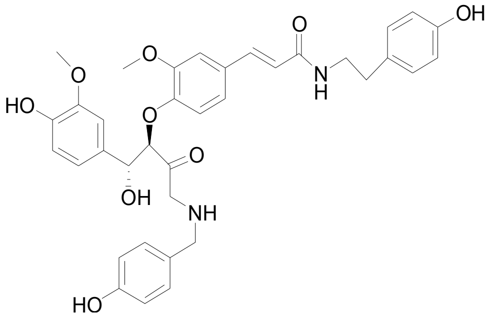
135 *N*-(4-*O*-(β-D-Glucopyranosyl)-*E*-feruloyl)-tyramine



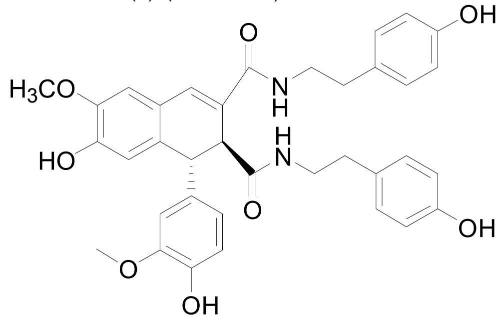
136 *N*-*E*-feruloyl-4-*O*-(β-D-glucopyranosyl)tyramine



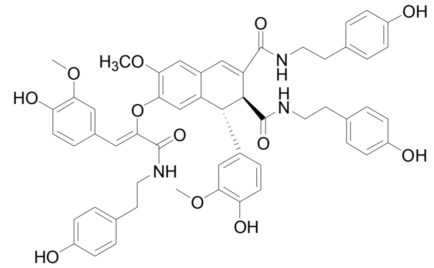
137 (±)-(7″*R**,8″R*)-Canabisine H



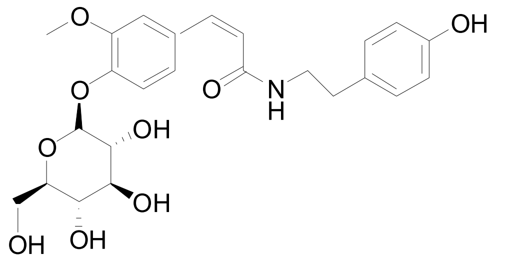
138 (±)-Cannabisin E



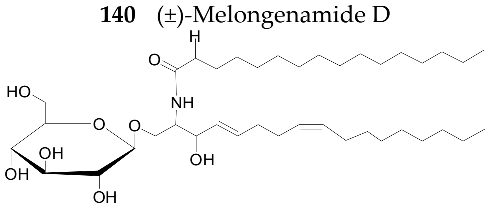
139 (±)-Cannabisin D



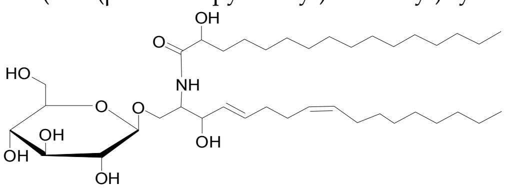
140 (±)-Melongenamide D



141 *N*-(4-*O*-(β-D-Glucopyranosyl)-*Z*-eruloyl)-tyramine



142 Cerebrosides A



143 Cerebrosides B

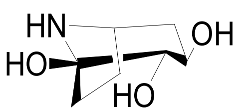
Figure 8. Chemical structures of compounds **107–143**.

2.2.7. Alkaloids **144–215**

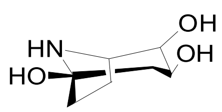
To date, 72 alkaloids have been identified, which can be classified into five categories: nortropane, imidazole, piperidine, pyrrole, spermine, tropane, and other alkaloids.

Nortropane Alkaloids

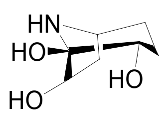
Fourteen nortropane alkaloids **144–157**, shiwn in Figure 9, have been isolated from the root bark of *L. chinense* [90].



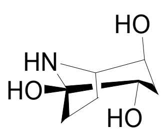
144 Calystegine A3



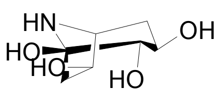
145 Calystegine A5



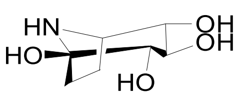
146 Calystegine A6



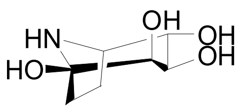
147 Calystegine A7



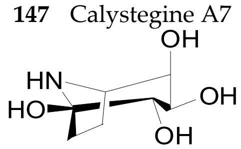
148 Calystegine B1



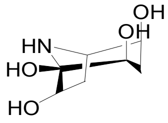
149 Calystegine B2



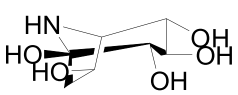
150 Calystegine B3



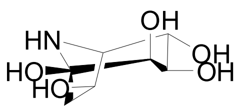
151 Calystegine B4



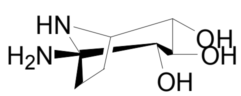
152 Calystegine B5



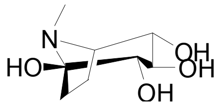
153 Calystegine C1



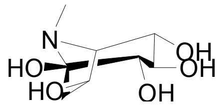
154 Calystegine C2



155 Calystegine N1



156 *N*-Methylcalystegine B2

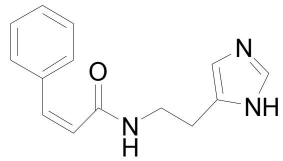


157 *N*-Methylcalystegine C1

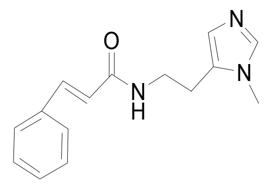
Figure 9. Chemical structures of compounds **144–157**.

Imidazole Alkaloids

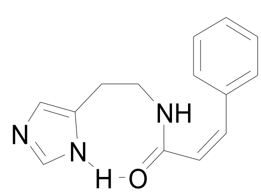
Six imidazole alkaloids **158–162** were detected in the leaves of *L. cestroides* [91]: Meanwhile, one imidazole, Na-[(*E*)-cinnamoyl]histamine (**163**), was obtained from the leaves of *L. barbarum* [66], listed in Figure 10.



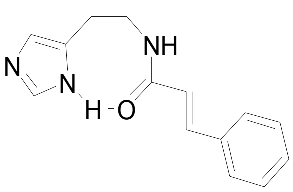
158 Na-[(*Z*)-Cinnamoyl]histamine



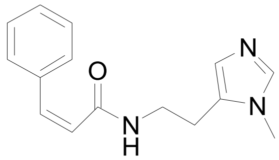
159 Na-[(*E*)-Cinnamoyl]-*N*1-methylhistamine



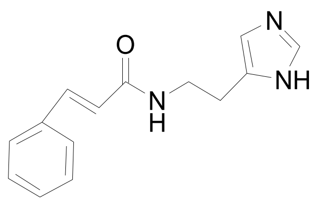
160 (*Z*)-Quasibicyclic



161 (*E*)-Quasibicyclic



162 Na-[(*Z*)-Cinnamoyl]-*N*1-methylhistamine

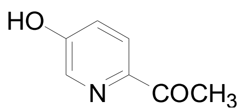


163 Na-[(*E*)-Cinnamoyl]-histamine

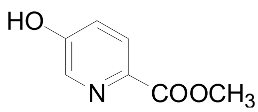
Figure 10. Chemical structures of compounds **158–163**.

Piperidine Alkaloids

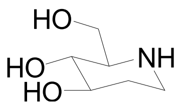
5-hydroxy-2-pyridylmethyl ketone (**164**), methyl 5-hydroxy-2-pyridinecarboxylate (**165**), fagomine (**166**), and 6-deoxyfagomine (**167**), listed in Figure 11, have been isolated and identified from the genus *Lycium*; among them. Compounds **164** and **165** are from the fruits of *L. barbarum* [92], and **166** and **167** are from the root bark of *L. chinense* [90].



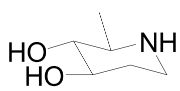
164 5-Hydroxy-2-pyridyl-methyl ketone



165 Methyl 5-hydroxy-2-pyridinecarboxylate



166 Fagomine



167 6-Deoxyfagomine

Figure 11. Chemical structures of compounds **164–167**.

Pyrrole Alkaloids

Thirteen pyrrole alkaloids **168–180** have been isolated from the fruits of *L. chinense* [93–95]. Likewise, 2-formyl-5-hydroxymethylpyrrole (**181**) and 2-formyl-5-methoxymethylpyrrole (**182**) were isolated from the fruits of *L. barbarum* [92]. Two pyrrolidine alkaloids, alkaloid I (**183**) and alkaloid II (**184**), are obtained from the root bark of *L. chinense* [96]. The chemical structures of these pyrrole alkaloids are listed in Figure 12.

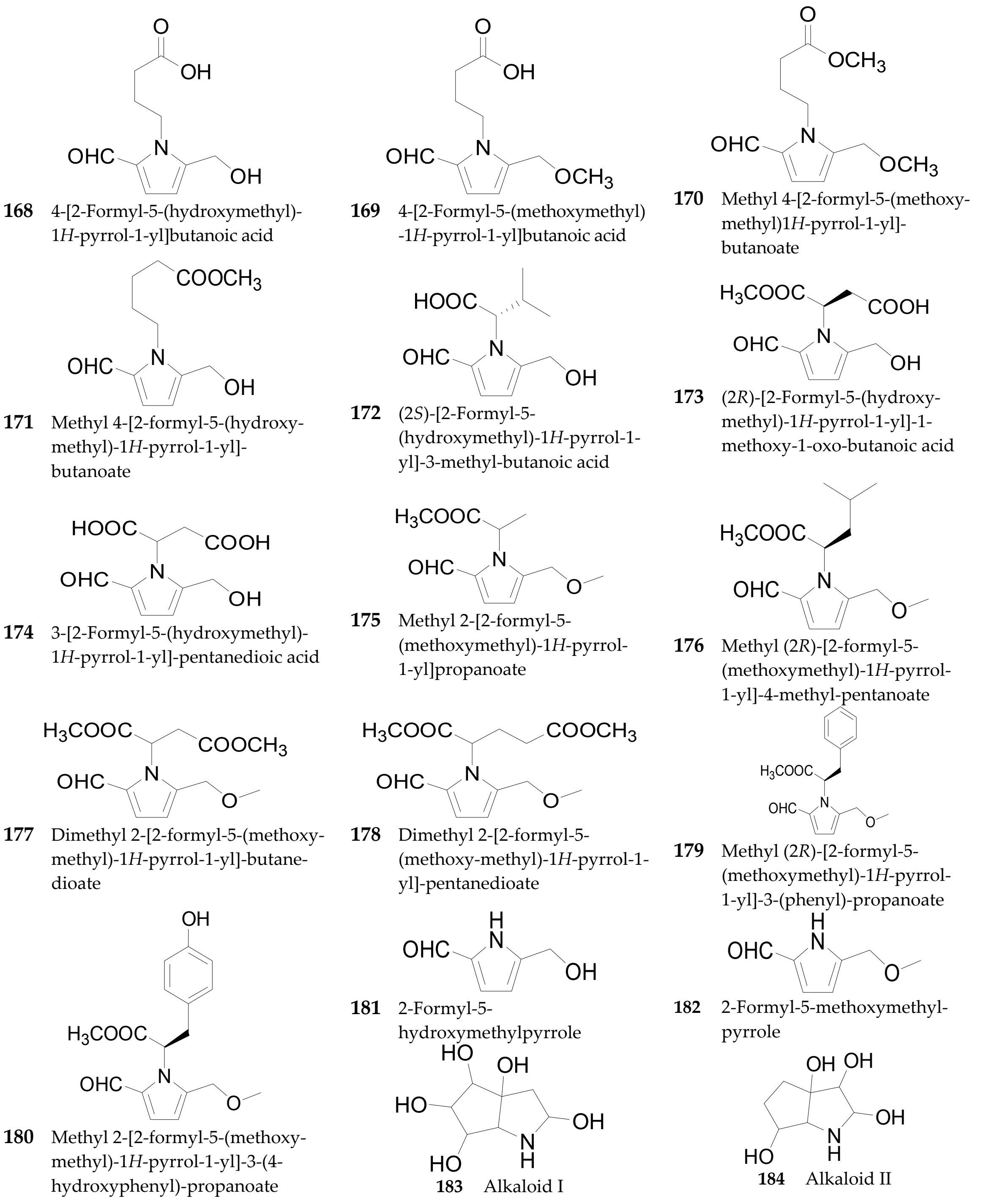
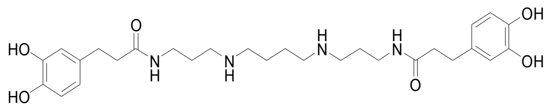


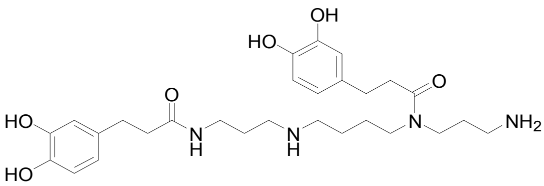
Figure 12. Chemical structures of compounds **168–184**.

Spermine Alkaloids

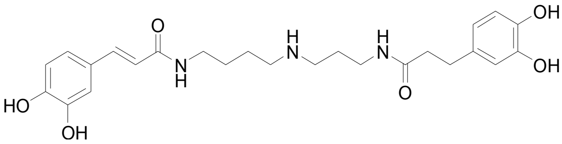
Nineteen spermine alkaloids have been found in the genus *Lycium*. Kukoamines A (**185**) and kukoamines B (**186**) are from the root bark of *L. chinense* [97,98], while *N*1-caffeoyl-*N*3-dihydrocaffeoyl spermidine (**187**) and lyrium spermidine A (**188**) are from the fruits of *L. ruthenicum* [62,99], listed in Figure 13. Another 15 spermine alkaloids, lycibarbarspermidine A–O (**189–203**), listed in Tables 9 and 10 and Figures 13–15, are from *L. barbarum* [100].



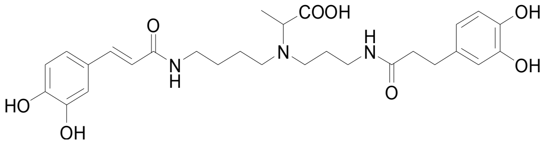
185 Kukoamines A



186 Kukoamines B



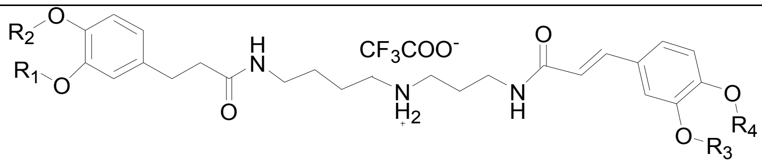
187 *N*1-Caffeoyl-*N*3-dihydrocaffeoyl spermidine



188 Lyrium spermidine A

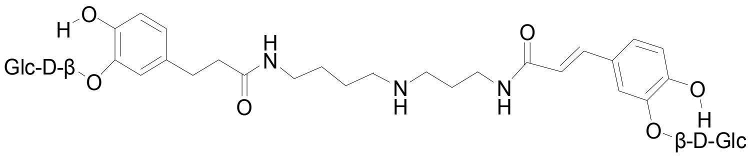
Figure 13. Chemical structures of compounds **185–188**.

Table 9. Chemical structures of compounds **189–193**.

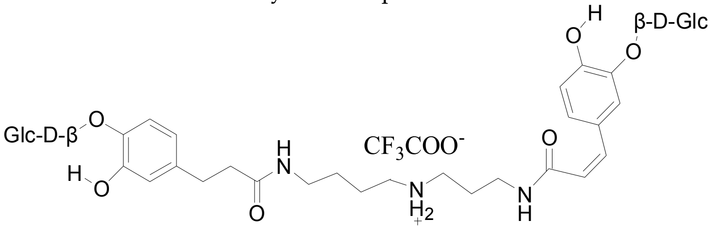


189–193

No.	Compounds	R_1	R_2	R_3	R_4	Source
189	Lycibarbarspermidine A	H	β-D-Glc	H	H	*L. barbarum*
190	Lycibarbarspermidine B	H	H	β-D-Glc	H	*L. barbarum*
191	Lycibarbarspermidine C	β-D-Glc	H	H	H	*L. barbarum*
192	Lycibarbarspermidine D	H	H	H	β-D-Glc	*L. barbarum*
193	Lycibarbarspermidine E	H	β-D-Glc	β-D-Glc	H	*L. barbarum*



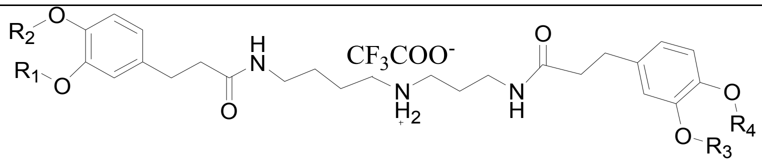
194 Lycibarbarspermidine F



195 Lycibarbarspermidine G

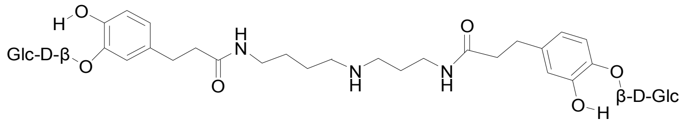
Figure 14. Chemical structures of compounds **194** and **195**.

Table 10. Chemical structures of compounds **196–200**.

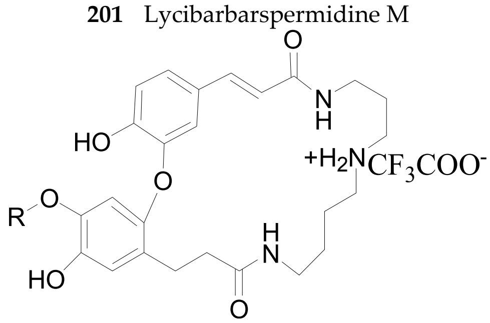


196–200

No.	Compounds	R_1	R_2	R_3	R_4	Source
196	Lycibarbarspermidine H	H	H	H	β-D-Glc	*L. barbarum*
197	Lycibarbarspermidine I	H	β-D-Glc	H	H	*L. barbarum*
198	Lycibarbarspermidine J	H	*H*	β-D-Glc	H	*L. barbarum*
199	Lycibarbarspermidine K	β-D-Glc	*H*	β-D-Glc	H	*L. barbarum*
200	Lycibarbarspermidine L	H	β-D-Glc	H	β-D-Glc	*L. barbarum*



201 Lycibarbarspermidine M



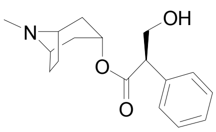
202 Lycibarbarspermidine N R = β-D-Glc
203 Lycibarbarspermidine O R = β-D-Glc[3]β-D-Glc

Figure 15. Chemical structures of compounds **201–203**.

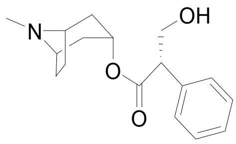
Tropane Alkaloids

As we know, the genus *Lycium* has been used as both a medicine and a food for a long time in Asia, particularly in China. However, the safety of *Lycium* has been questioned for some time, especially after the detection of the three tropane alkaloids atropine (**204**), hyoscyamine (**205**), and scopolamine (**206**) [101]. Atropine and hyoscyamine were identified from the fruits of *L. barbarum* gathered in India, while scopolamine was identified from *L. halimifolium* at concentrations higher than the toxic dose. However, another scholar, seeking to verify these reports, demonstrated that the atropine content of *L. barbarum* from different sources was just 3.0 ppb—far below the poisoning dose [102]. It was demonstrated that none of the toxic compounds were detected in fruits, leaves, stems and roots of three *L. barbarum* varieties ('No. 1', 'New Big' and 'Amber Sweet Goji') by densitometric TLC analysis [103]. Through field investigation and model specimen inspections, the above three tropane alkaloids were determined to be from *Lycium europaeum* rather than the *L. barbarum*. Thus, the genus *Lycium* is likely non-toxic, and consumers can rest assured that its use is safe [104].

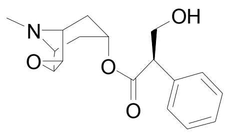
Other than the alkaloids that have been already mentioned, there are nine others that have been obtained from this genus, including 9-formylharman (**207**), 1-(methoxycarbonyl)-β-carboline (**208**), perlolyrine (**209**), choline (**210**), 1β-amino-3β,4β,5α-trihydroxycycloheptane (**211**), betaine hydrochloride (**212**), nicotianamine (**213**), betaine (**214**), and melatonin (**215**). Compounds **207–209** were isolated from the fruits of *L. chinense* [105], while **210–212** were isolated from the root bark of *L. chinense* [90]. Compound **213** was isolated from the leaves and flowers of *L. chinense* [106], and **214** and **215** were isolated from the fruits of *L. barbarum* [107,108]. The chemical structures of these tropane alkaloids are listed in Figure 16.



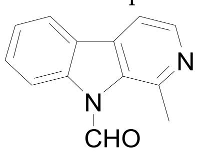
204 Atropine



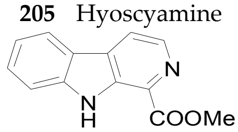
205 Hyoscyamine



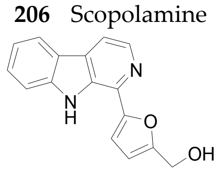
206 Scopolamine



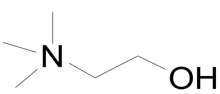
207 9-Formylharman



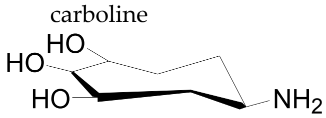
208 1-(Methoxycarbonyl)-β-carboline



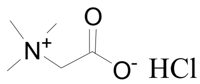
209 Perlolyrine



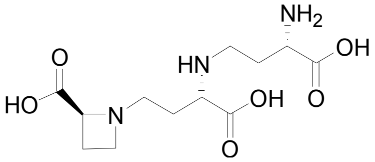
210 Choline



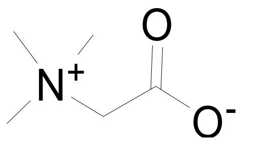
211 1β-Amino-3β,4β,5α-trihydroxycycloheptane



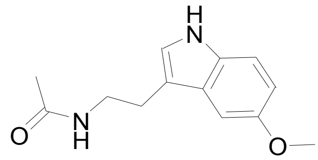
212 Betaine hydrochloride



213 Nicotianamine



214 Betaine

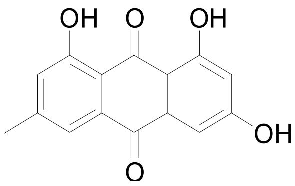


215 Melatonin

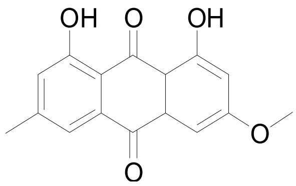
Figure 16. Chemical structures of compounds **204–215**.

2.2.8. Anthraquinones 216–219

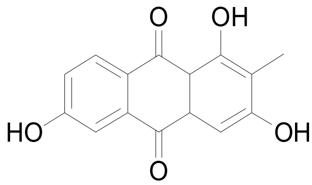
Four anthraquinones: emodin (**216**), physcion (**217**), 6-hydroxyrubiadin (**218**), and 3-*O*-(2-*O*-α-L-rhamnopyranosyl-6-*O*-acetyl-β-D-glucopyranosyl)-6-hydroxy-rubiadin (**219**), listed in Figure 17, have been obtained from the root bark of *L. chinense* [61,109].



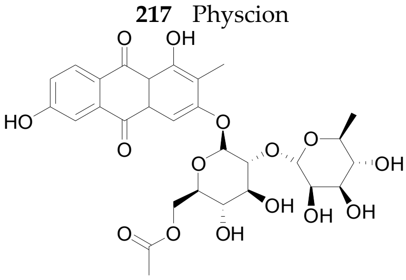
216 Emodin



217 Physcion



218 6-Hydroxyrubiadin

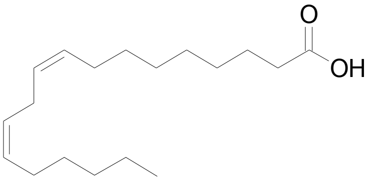


219 3-*O*-(2-*O*-α-L-Rhamnopyranosyl-6-*O*-acetyl-β-D-glucopyranosyl)-6-hydroxyrubiadin

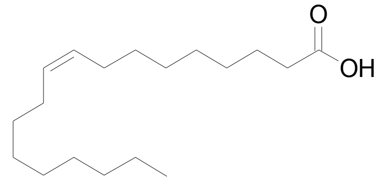
Figure 17. Chemical structures of compounds **216–219**.

2.2.9. Organic Acids 220–251

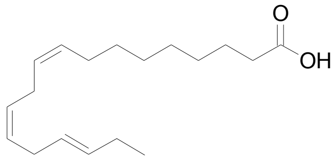
To this point, 32 organic acids, listed in Figure 18, have been identified from the genus *Lycium*, which can be classified into two groups: aliphatic acids **220–238** and aromatic acids and their derivatives **239–251**. Compounds **220–225** and **240–244** were isolated from the fruits of *L. barbarum* [56,63,65,107,110–112]; **239** and **245** were isolated from the leaves of *L. barbarum* [66]; **226** was isolated from the root of *L. chinense* [113]; **227**, **248** and **249** were isolated from the fruits of *L. chinense* [70,114]; **228–233** and **248** were isolated from the leaves of *L. chinense* [115]; **234**, **235**, and **249–251** were isolated from the root bark of *L. chinense* [53,78,93,116,117], and **236–238** were isolated from the fruits of *L. urcomanicum* [118,119].



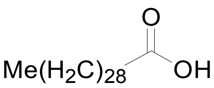
220 Linoleic acid



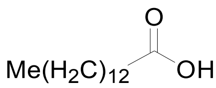
221 Oleic acid



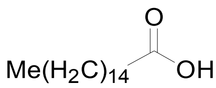
222 Linolenic acid



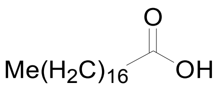
223 Melissic acid



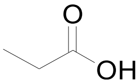
224 Myristic acid



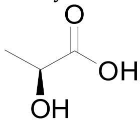
225 Palmitic acid



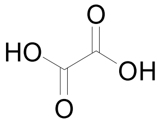
226 Stearic acid



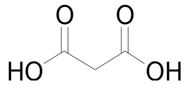
227 Pentanoic acid



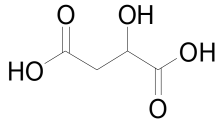
228 Lactic acid



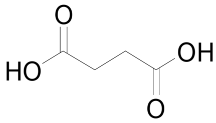
229 Oxalic acid



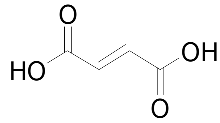
230 Malonic acid



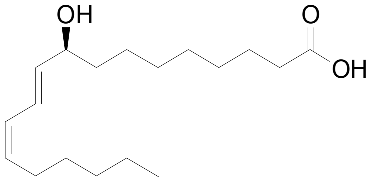
231 Malic acid



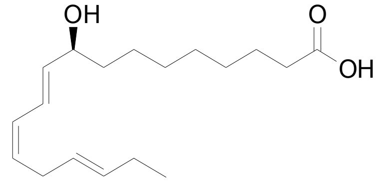
232 Succinic acid



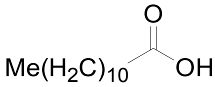
233 Fumaric acid



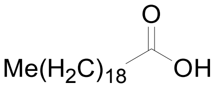
234 Dimorphecolic acid



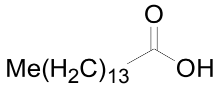
235 (9*S*,10*E*,12*Z*,15*Z*)-9-Hydroxyoctadeca-10,12,15-trienoic acid



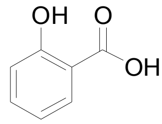
236 Dodecanoic acid



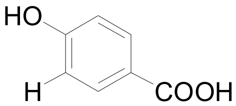
237 Arachidic acid



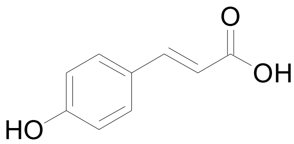
238 Pentadecanoic acid



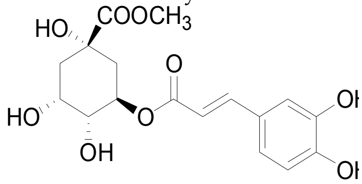
239 Salicylic acid



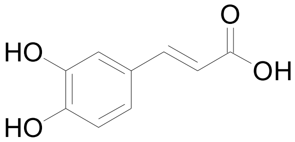
240 *p*-Hydroxybenzoic acid



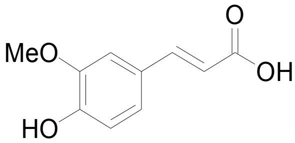
241 *p*-Coumaric acid



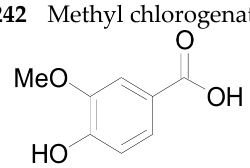
242 Methyl chlorogenate



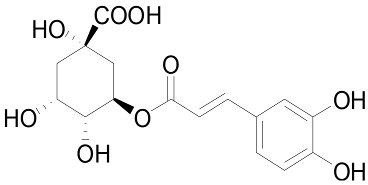
243 Caffeic acid



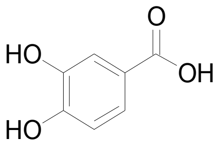
244 Ferulic acid



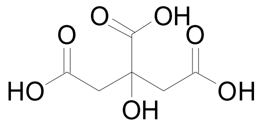
245 Vanillic acid



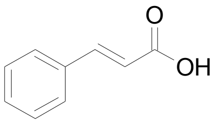
246 Chlorogenic acid



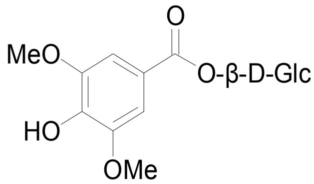
247 Protocatechuic acid



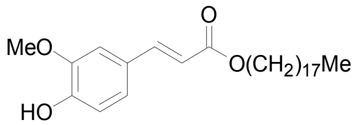
248 Citric acid



249 Cinnamic acid



250 β-D-Glucopyranosyl syringate

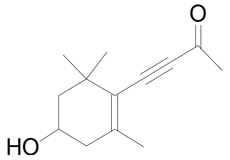


251 Stearyl ferulate

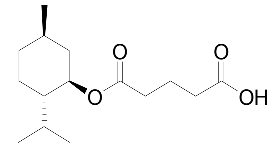
Figure 18. Chemical structures of compounds **220–251**.

2.2.10. Terpenoids **252–290**

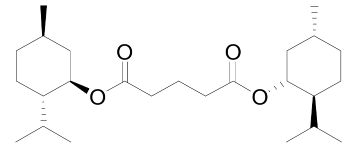
Thirty-seven terpenoids, listed in Figures 19–21 and Tables 11 and 12, have been found in the genus *Lycium*, mainly including monoterpenes **252–256**, sesquiterpenes **257–263**, diterpenoids **264–274**, and carotenoids **275–290**. Among them, carotenoids are one of the more important constituents of the *Lycium* fruits. Thus compounds **256** and **275–286** were isolated from the fruits of *L. barbarum* [120–123]; **253**, **254**, **258**, **259** and **287–290** were isolated from the fruits of *L. chinense* [120,121,124–126]; **252** and **264–272** were isolated from the leaves of *L. chinense* [127,128]; **255**, **258** and **273–274** were isolated from the root bark of *L. chinense* [80,116]; **260** and **261** were isolated from the leaves of *L. halimifolium* [23]; and **262** and **265** were isolated from the leaves of *L. barbarum* [129].



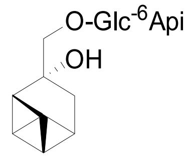
252 7,8-Dihydro-3-hydroxy-β-ionone



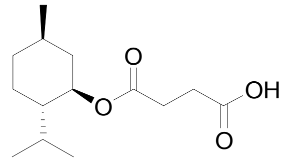
253 L-Monomethyl glutarate



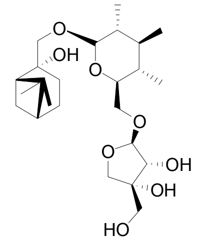
254 L-Dimethyl glutarate



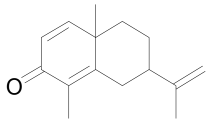
255 Monoterpene glycoside



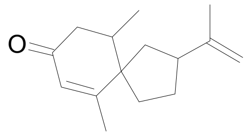
256 L-Monomethyl succinate



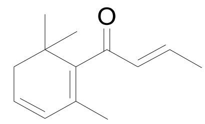
257 10-*O*-(β-D-Apiofuranosyl)-(1 → 6)-(β-D-glucopyranosyl)-pinanediol



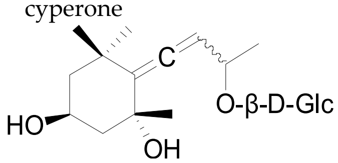
258 (-)-1,2-Didehydro-α-cyperone



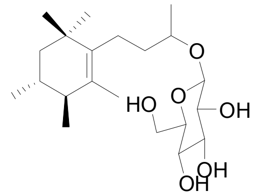
259 Solavetivone



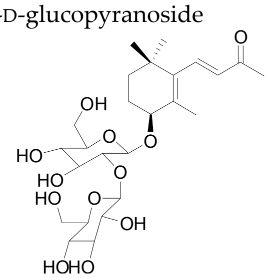
260 Damascenone



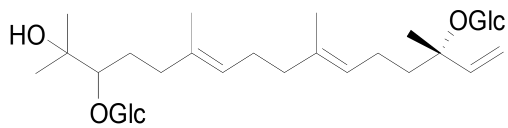
261 3-(2,4-Dihydroxy-2,6,6-trimethylcyclohexylidene)-1-methylprop-2-enyl-β-D-glucopyranoside



262 Lyciumionoside A



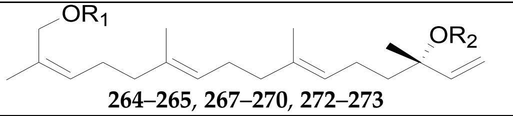
263 Lyciumionoside B



266 Lyciumosides III

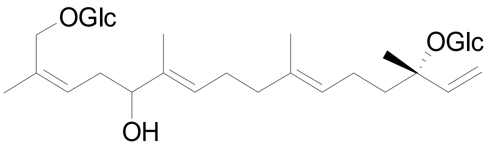
Figure 19. Chemical structures of compounds **252–263**, **266**.

Table 11. Chemical structures of compounds **264–265**, **267–270** and **272–273**.

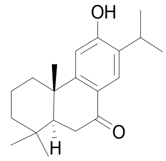


264–265, 267–270, 272–273

No.	Compounds	R_1	R_2	Source
264	Lyciumosides I	Glc	Glc	*L. chinense*
265	Lyciumosides II	Glc^2-Glc	Glc	*L. chinense*
267	Lyciumosides IV	Glc	Glc^4-Rha	*L. chinense*
268	Lyciumosides V	Glc^6-Rha	Glc	*L. chinense*
269	Lyciumosides VI	Glc^6-Rha	Glc^4-Rha	*L. chinense*
270	Lyciumosides VII	Glc^2-Rha(^{6}-Glc)	Glc	*L. chinense*
272	Lyciumosides IX	Glc	6-*O*-malonyl-Glc	*L. chinense*
273	Capsianoside II	Rha^3-Glc^6-Rha	Glc^2-Glc	*L. chinense*



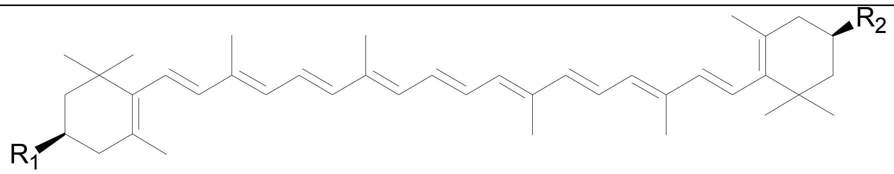
271 Lyciumosides VIII



274 Diterpene sugiol

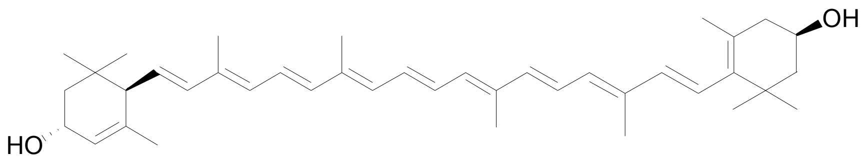
Figure 20. Chemical structures of compounds **271** and **274**.

Table 12. Chemical structures of compounds **275–282**.

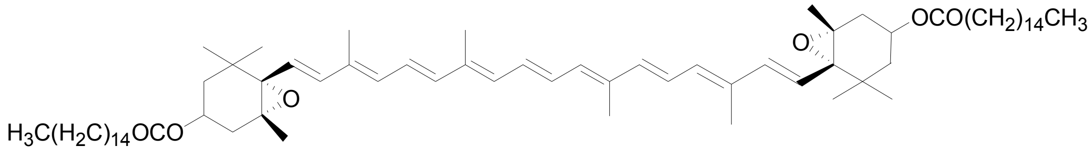


275–282

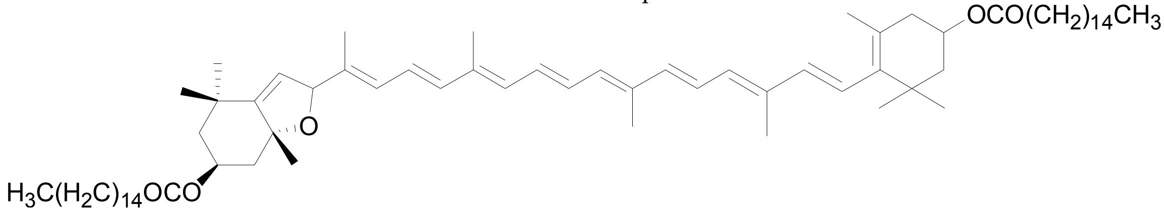
No.	Compounds	R1	R2	Source
275	β-Carotene	H	H	*L. barbarum*
276	β-Cryptoxanthin	OH	H	*L. barbarum*
277	Zeaxanthin	OH	OH	*L. barbarum*
278	Zeaxanthin monopalmitate	$OCO(CH_2)_{14}CH_3$	OH	*L. barbarum*
279	Zeaxanthin dipalmitate	$OCO(CH_2)_{14}CH_3$	$OCO(CH_2)_{14}CH_3$	*L. barbarum*
280	Zeaxanthin monomyristate	OH	$OCO(CH_2)_{12}CH_3$	*L. barbarum*
281	Zeaxanthin dimyristate	$OCO(CH_2)_{12}CH_3$	$OCO(CH_2)_{12}CH_3$	*L. barbarum*
282	β-Cryptoxanthin palmitate	$OCO(CH_2)_{14}CH_3$	H	*L. barbarum*



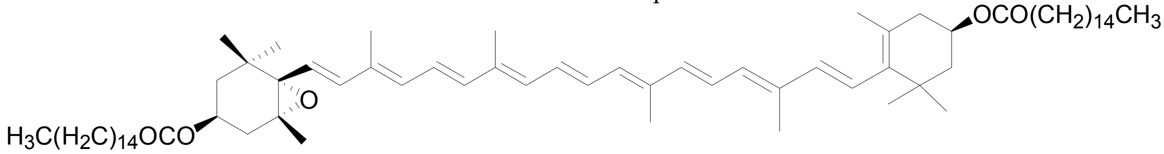
283 Lutin



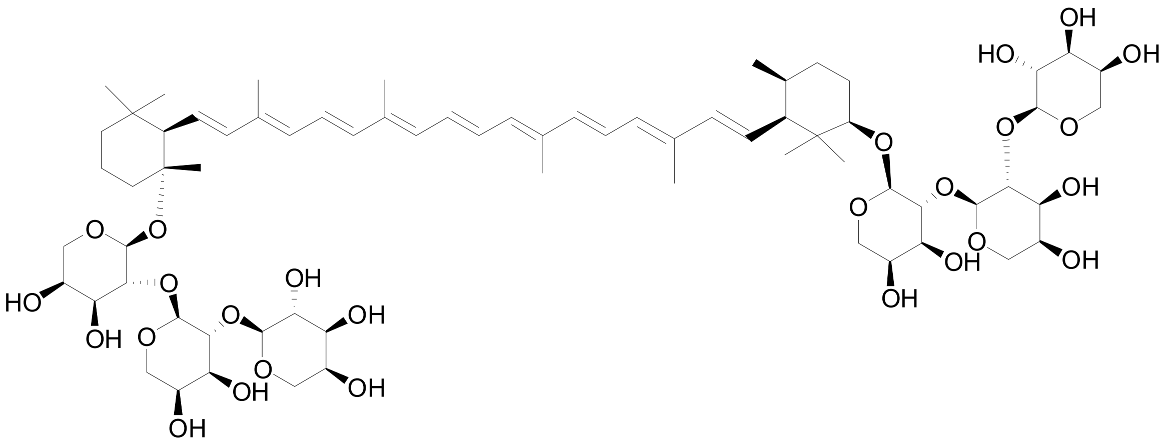
284 Violaxanthin dipalmitate



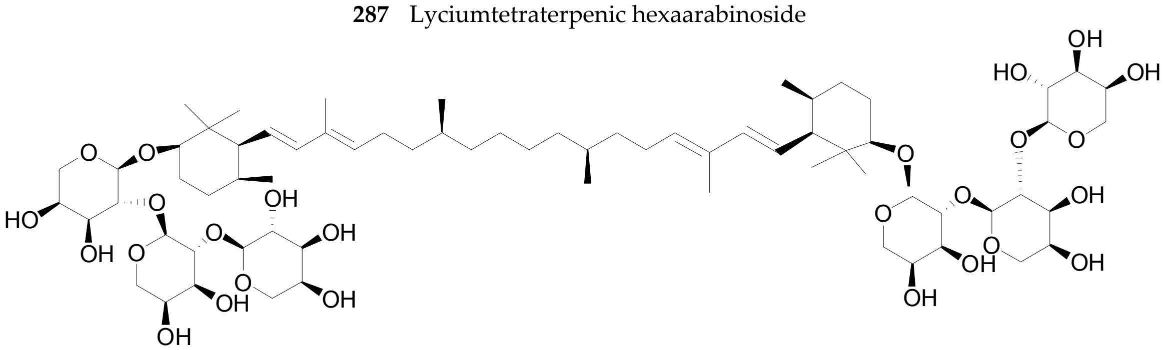
285 Mutatoxanthin dipalmitate



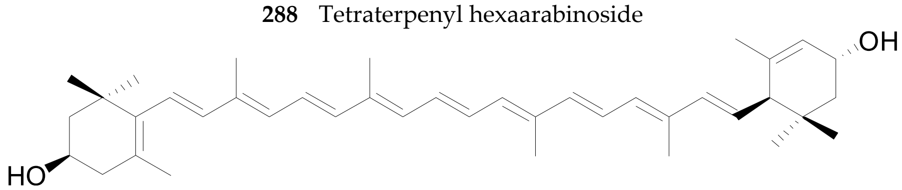
286 Antheraxanthin dipalmitate



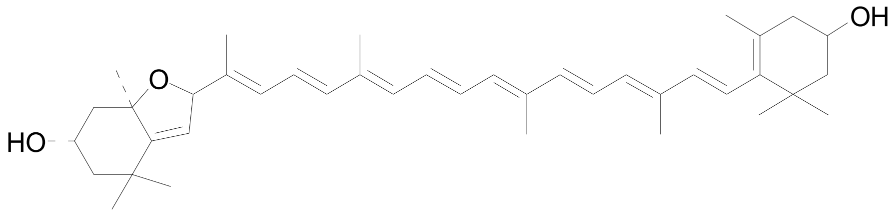
287 Lyciumtetraterpenic hexaarabinoside



288 Tetraterpenyl hexaarabinoside



289 Lutein

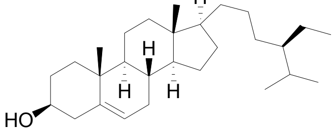


290 Mutatoxanthin

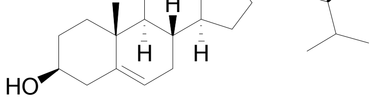
Figure 21. Chemical structures of compounds **283–290**.

2.2.11. Sterols, Steroids, and Their Derivatives **291–347**

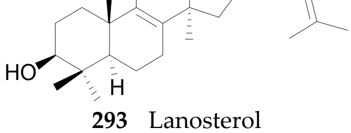
Fifty-seven sterols, steroids, and their derivatives **291–347**, listed in Figure 22, have been identified from the genus *Lycium*, mainly from the seeds and the fruits. Compounds **293** and **343** were identified from the flowers of *L. barbarum* [130], **291–292**; **295**, **298**, **319–324** and **337–339** were identified from the fruits of *L. chinense* [23,35,52,63,107,131]; **341 342**, **346** and **347** were identified from the leaves of *L. chinense* [132,133]; **336** and **340** were identified from the root bark of *L. chinense* [80,121]; **294** was identified from the seed of *L. ciliatum* [66]; all others were identified from the seed of *L. chinense* [134–137] **344** and **345** were identified from the seeds of *L. barbarum* [138].



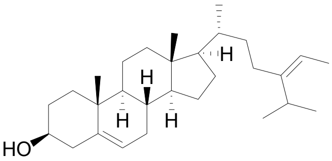
291 β-Sitosterol



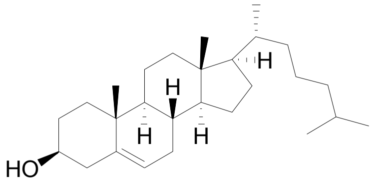
292 Campesterol



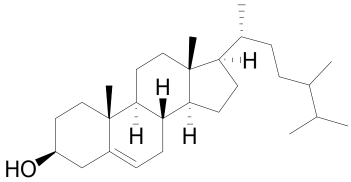
293 Lanosterol



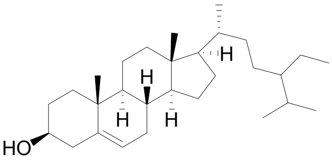
294 24-Ethylidenecholesterol



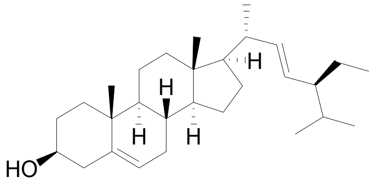
295 Cholesterol



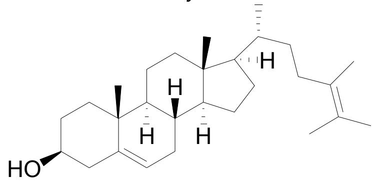
296 24-Methylcholesterol



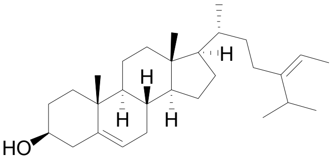
297 24-Ethylcholesterol



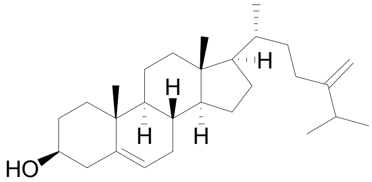
298 Stigmasterol



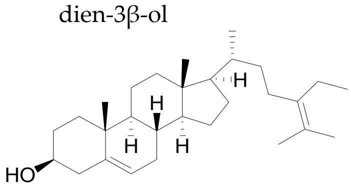
299 24-Methylcholesta-5,24-dien-3β-ol



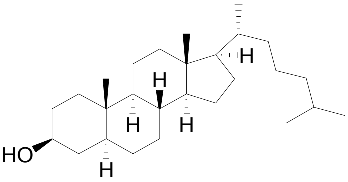
300 28-Isofucosterol



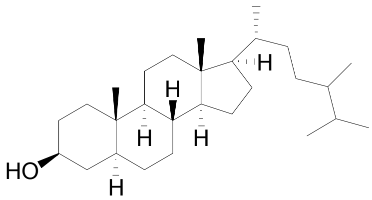
301 24-Methylidenecholesterol



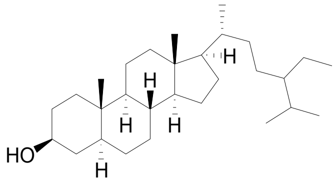
302 24-Ethylcholesta-5,24-dien-3β-ol



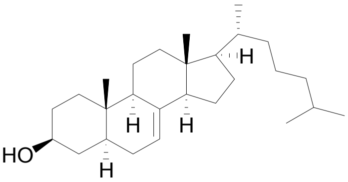
303 Cholestan-3β-ol



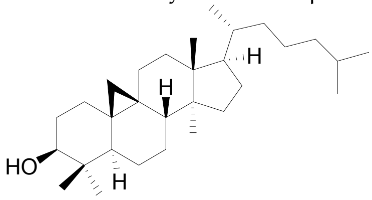
304 24-Methylcholestan-3β-ol



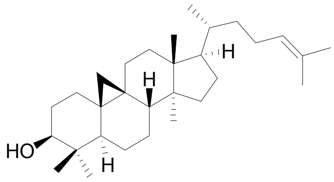
305 24-Ethylcholestan-3β-ol



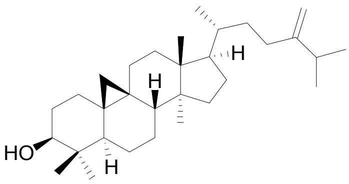
306 Cholest-7-en-3β-ol



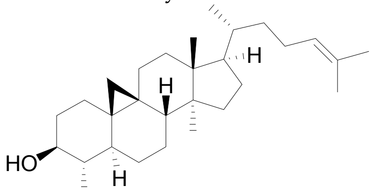
307 Cycloartanol



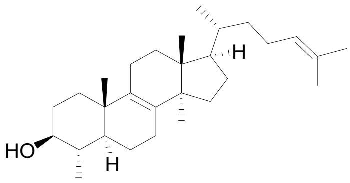
308 Cycloartenol



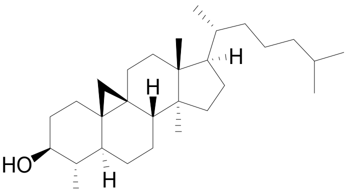
309 24-Methylidenecycloartanol



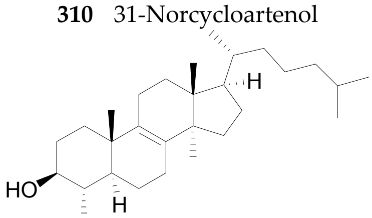
310 31-Norcycloartenol



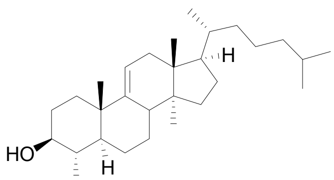
311 31-Norlanosterol



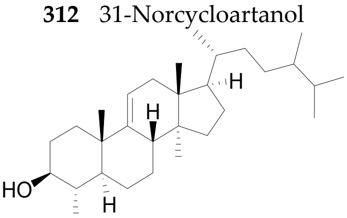
312 31-Norcycloartanol



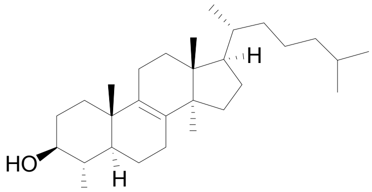
313 31-Norlanost-8-enol



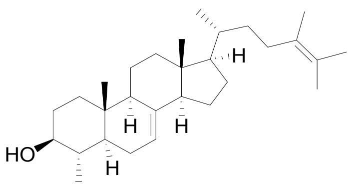
314 31-Norlanost-9(11)-enol



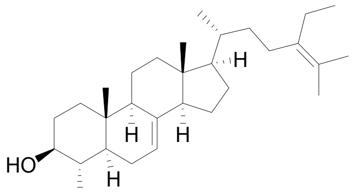
315 24-Methyl-31-norlanost-9(11)-enol



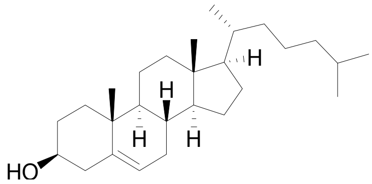
316 4α-Methylcholest-8-en-3β-ol



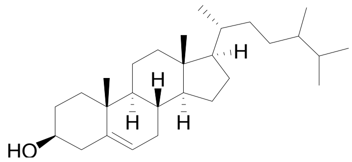
317 4α-24-Dimethylcholesta-7,24-dien-3β-ol



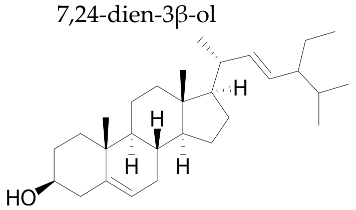
318 24-Ethyl-4α-methylcholesta-7,24-dien-3β-ol



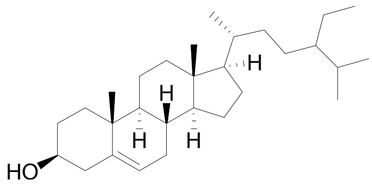
319 Cholest-5-en-3β-ol



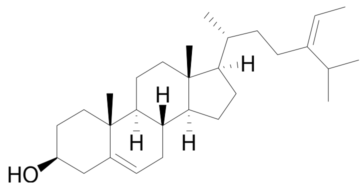
320 24-Methylcholest-5-en-3β-ol



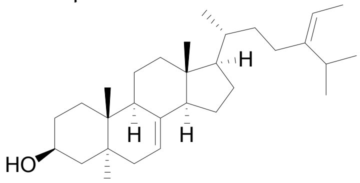
321 24-Ethylcholesta-5,22-dien-3β-ol



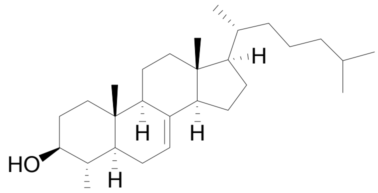
322 24-Ethylcholest-5-en-3β-ol



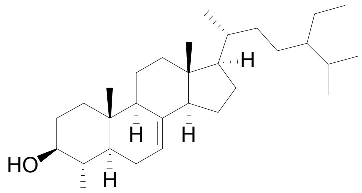
323 24-Ethylidenecholest-5-en-3β-ol



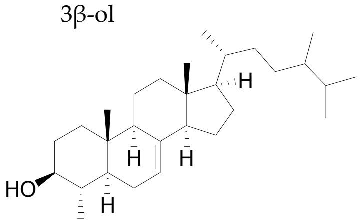
324 24-Ethylidenecholest-7-en-3β-ol



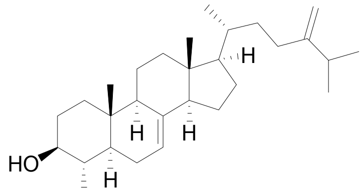
325 Lophenol



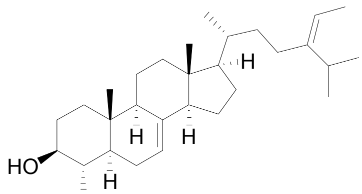
326 24-Ethyllophenol



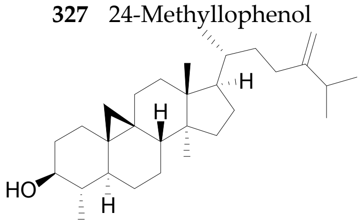
327 24-Methyllophenol



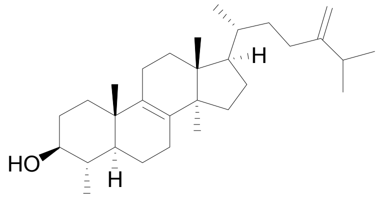
328 Gramisterol



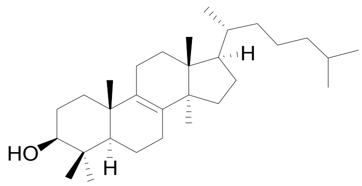
329 Citrostadienol



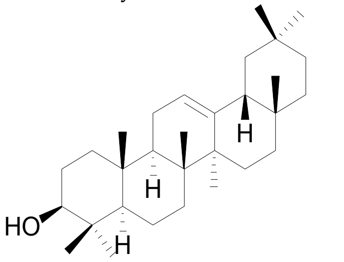
330 Cycloeucalenol



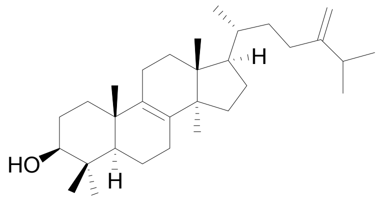
331 Obtusifoliol



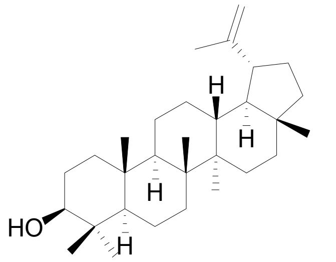
332 Lanost-8-enol



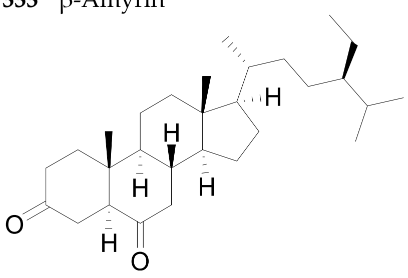
333 β-Amyrin



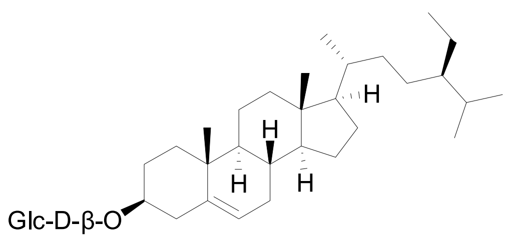
334 24-Methylenelanost-8-enol(24-methylenelanost-8-en-3β-ol)



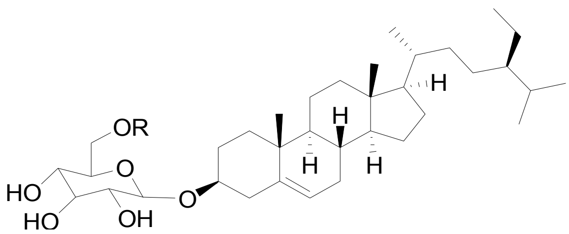
335 Lupeol



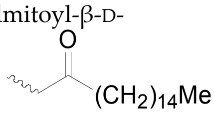
336 5α-Stigmastane-3,6-dione



337 β-Sitosterol β-D-glucopyranoside

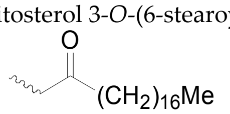


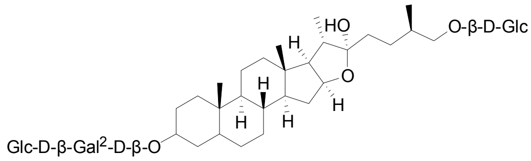
338 β-Sitosterol 3-*O*-(6-palmitoyl-β-D-glucopyranoside) R =



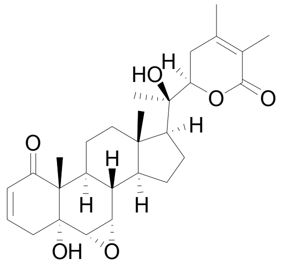
339 β-Sitosterol 3-*O*-(6-stearoyl-β-D-glucopyranoside)

R =

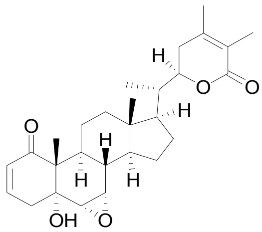




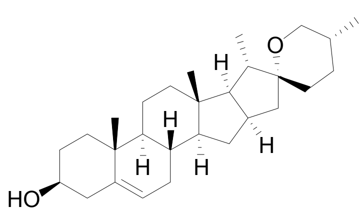
340 Furostanol glycoside R_1 = β-D-Gal²-β-D-Glc, R_2 = β-D-Glc



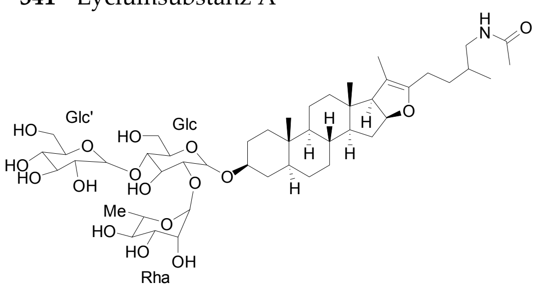
341 Lyciumsubstanz A



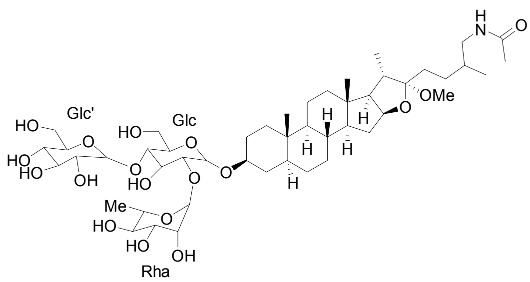
342 Lyciumsubstanz B



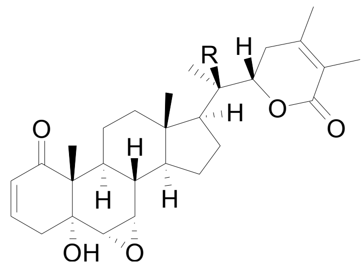
343 Diosgenin



344 Lycioside A



345 Lycioside B



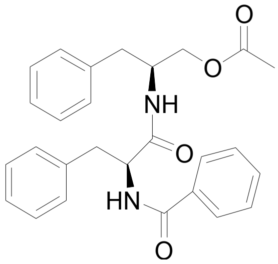
346 Withanolide A R=OH

347 Withanolide B R=H

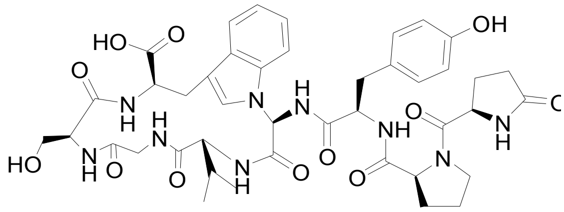
Figure 22. Chemical structures of compounds **291**–**347**.

2.2.12. Peptides 348–352

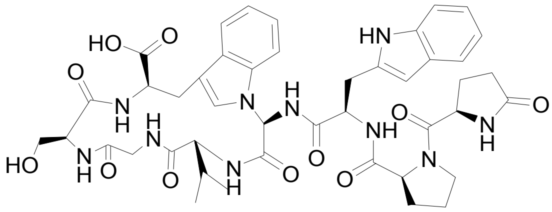
Five peptides have been isolated from the root bark of *L. chinense* [80,139], including one dipeptide, lyciumamide (**348**), and four octapeptides, called lyciumins A–D (compounds **349**–**350**), illustrated in Figure 23.



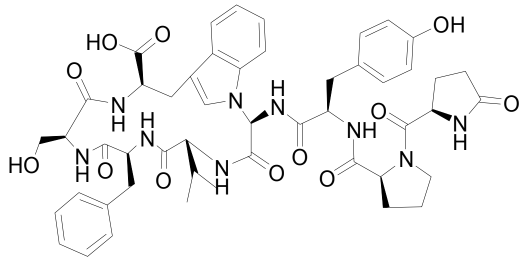
348 Lyciumamide



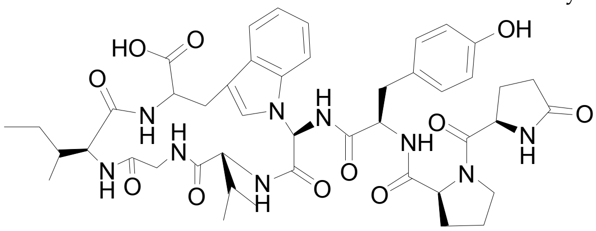
349 Lyciumins A



350 Lyciumins B



351 Lyciumins C

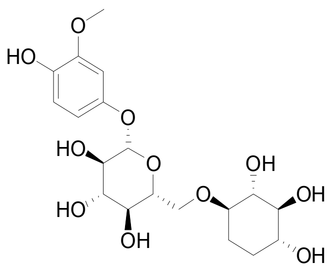


352 Lyciumins D

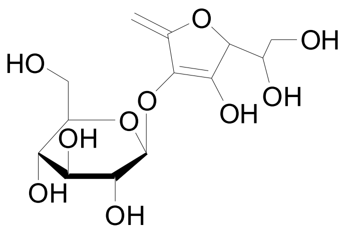
Figure 23. Chemical structures of compounds **348**–**352**.

2.2.13. Other Compounds **353**–**355**

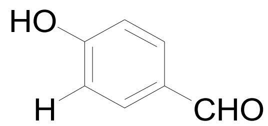
Other than what has already been mentioned, a few other chemical constituents, listed in Figure 24, were also isolated from the genus *Lycium*. Digupigan A (**353**), 2-*O*-(β-D-glucopyranosyl)ascorbic acid (**354**) and *p*-hydroxybenzaldehyde (**355**) also have been obtained from the root bark of *L. chinense*, the fruits of *L. chinense,* and the fruits of *L. barbarum* [75,76,121,137,140,141], respectively. Many minerals, amino acids, and proteins have also been found in the genus *Lycium,* such as Ca, Mg, Zn, Fe, aminoethanesulfonic acid, γ-aminobutyric acid (GABA), Mn-SOD, etc. [121,142,143].



353 Digupigan A



354 2-*O*-(β-D-Glucopyranosyl)-ascorbic acid



355 *p*-Hydroxybenzaldehyde

Figure 24. Chemical structures of compounds **353**–**355**.

3. Discussion

Lycium species are of valuable medicinal, nutritional and functional significance, and have been studied in terms of their chemical compounds. Phytochemical investigations on eight different species, have resulted in the isolation of at least **355** constituents up to July of 2016. Research on chemical compounds has concentrated mainly on *L. barbarum* and *L. chinense*. Therefore, future phytochemistry research should be focused on the other species in *Lycium* genus. In addition, diverse plant parts (i.e., the flowers, leaves, seeds) have also been testified to contain new constituents, most of which possess the novel chemical structures. Polysaccharides play a particularly significant role in exerting pharmacological actions. A specific class of polysaccharides, abbreviated as LBP, is used as biomarker in the 2015 Chinese Pharmacopoeia as a measure by which wolfberry is qualified. At present, LBP in products or in pharmacological studies usually are polysaccharide mixtures with heterogeneity and polydispersity. On the other hand, development of new separation, detection techniques will greatly benefit the phytochemical isolation and structural elucidation of LBP. There is a growing recognition that not only the LBP, but also the plant secondary metabolites may have the potential active ingredients, while most of the research on goji berry was LBP rather than small molecule substances, so more intensive studies of goji berry are required to shed some light on these compounds.

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Conflicts of Interest: The authors declare no conflict of interest.

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