Chinese Herbal Medicines 16 (2024) 70–81

Contents lists available at ScienceDirect

Chinese Herbal Medicines

journal homepage: www.elsevier.com/locate/chmed

Review

Chemical composition and pharmacological activity of seco-prezizaane-type sesquiterpenes

Ye Jin [a], Yanqing Xie [a], Peng Zhang [a], Afsar Khan [b], Zhihong Zhou [a], Lu Liu [a,*]

[a] Yunnan Yunzhong Institute of Nutrition and Health, Yunnan University of Chinese Medicine, Kunming 650500, China
[b] Department of Chemistry, COMSATS University Islamabad, Abbottabad Campus, Abbottabad 22060, Pakistan

ARTICLE INFO

Article history:
Received 15 March 2023
Revised 2 June 2023
Accepted 26 June 2023
Available online 11 December 2023

Keywords:
anisatin
chemical composition
Illicium genus
majucin
pharmacological activity
seco-prezizaane-type sesquiterpenes

ABSTRACT

The seco-prezizaane-type sesquiterpenes (SPS), as a special class of sesquiterpenes with a highly oxidative five-ring cage structure and seven consecutive chiral centers, are isolated from the genus *Illicium*, which have a variety of biological activities, including neurotoxicity and neurotrophic effects, etc. This review summarizes the chemical constituents and pharmacological effects of SPS, and discusses the potential trend and scope of future research.

Contents

* Corresponding author.
E-mail address: todayliulu@163.com (L. Liu).

https://doi.org/10.1016/j.chmed.2023.06.003

1. Introduction

Seco-prezizaane-type sesquiterpenes (SPS, Fig. 1A), as a class of sesquiterpenes, are known to be derived from bond cleavage in the backbone of prezizaanes (Li, Shen, & Zhang, 2016), which have a highly oxygenated fused tetra- or penta-cyclic structure with several continuous stereo centers (Kawamura et al., 2019), originated from tricyclo [6.2.1.0^{1,5}] undecane skeleton (Fig. 1B). Since, (-)-anisatin was first isolated from the fruits of *Illicium anisatum* by Lane et al. in 1952, many SPS had been successively isolated from various members of *Illicium* in the past 60 years (Li, Shen, & Zhang, 2016). SPS are found only in the genus *Illicium* and are considered to be characteristic chemical markers of the genus (Liu et al., 2014; (Liu et al., 2020). Among of these, the representative compounds are jiadifenin, neomajucin and jiadifenolide, which have a strong neurotoxic or physiological activity against nerve growth (Cheng & Micalizio, 2014; Li, Shen, & Zhang, 2016).

The structure of SPS has the following characteristics: (1) it has a highly oxidized five-ring cage structure, including continuous and bridged rings, etc., (2) it contains seven continuous chiral centers, where the core six-membered B ring contains five chiral carbons, and four of them are quaternary carbons, (3) it contains a variety of oxygen-containing functional groups, including α-hydroxy lactone, α-arsenate, etc. (Li, Shen, & Zhang, 2016). SPS belong to a distinct structural type with a distinctive caged structure consisting of lactones, acetals, or orthostatic ester groups (Liu et al., 2020).

SPS have neurotrophic, neurotoxic, anti-inflammatory, insecticidal, sedative, and analgesic activities. Nowadays, neurotrophic agents are being selected as candidates for therapeutic strategies to control cerebral nerve loss in patients with Alzheimer's disease. Therefore, compounds with significant physiological activity in promoting the growth of primary cultured rat cortical neurons, such as jiadifenolide, can be used as small molecule neurotrophic agents or lead compounds to develop drugs for the treatment of Alzheimer's disease, Parkinson's disease, Huntington's disease, and other neurodegenerative diseases (Li, Shen, & Zhang, 2016). Meanwhile, the discovery of new activities with selective effects on hepatitis B virus and coxsackie virus B3 infection has increased the interest of researchers in such compounds.

In the paper, the chemical constituents and pharmacological effects of SPS are reviewed, and the potential trend and scope of future research are discussed.

2. Seco-prezizaane-type sesquiterpenes

Since 1952, more than 140 SPS have been reported and classified into six subtypes based on their core carbon framework and functional groups: anisatin, majucin, minwanensin (floridanolide), pseudoanisatin, pseudomajucin, and cycloparvi-floralone (Liu et al., 2020; Yin, Wang, Wang, & Kong, 2012; Zhu et al., 2009).

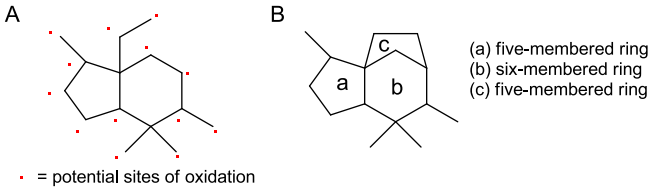


Fig. 1. (A) Seco-prezizaane-type sesquiterpenes; (B) Tricyclo [6.2.1.0^{1,5}] undecane.

The classification of SPS is based on their different cyclization modes, which might be helpful for the subsequent structural studies (Fig. 2).

2.1. C_7-C_{11} esterification

The structural feature of this type of compounds is mainly the formation of a δ-lactone ring after the ring opening at the C_7-C_{11} position (Fig. 3). They are mainly distributed in *I. floridanum* and *I. minwanense*, and some monomeric compounds have also been isolated from *I. merrillianum*, *I. lanceolatum*, and *I. ternstroemioides*. According to literature review, around 21 monomeric compounds of this type have been isolated so far.

2.1.1. C_{13}-C_{14} esterification

After the formation of a δ-lactone ring by ring opening at the C_7-C_{11} position, this type of compounds further undergoes C_{13}-C_{14} esterification to form a 13,14-β-lactone (Fig. 4). They are widely distributed, mainly in *I. majus*, and some monomeric compounds have also been isolated from *I. verum*, *I. anisatum*, and other plants. According to literature review, approximately 20 monomeric compounds of this type have been isolated so far.

2.1.2. C_{12}-C_{14} esterification

After the formation of a δ-lactone ring by ring opening at the C_7-C_{11} position, this type of compounds further undergoes C_{12}-C_{14} esterification to form a γ-lactone ring (Fig. 5). They are mainly distributed in *I. majus* and *I. jiadifengpi*. According to literature review, approximately 22 monomeric compounds of this type have been isolated so far.

2.2. C_{11}-C_{14} esterification

Some of these compounds also contain a 1,4-ether linkage and a 14,15-β-lactone, and some are found to coexist as ketones and acetals in equilibrium (Fig. 6). This type of compounds is mainly distributed in *I. merrillianum*, *I. anisatum*, and also found in other plants such as *I. minwanense* and *I. parviflorum*. According to literature review, approximately 29 monomeric compounds of this type have been isolated so far.

Acetal-hemiacetal and/or ortholactone: This class of sesquiterpenes has been reported to be composed of unique acetal-hemiacetal and/or ortholactone structure, and it can be expected that they may be in equilibrium between acetal-hemiacetal and aldehydes or between normal esters and lactones (Fig. 7). This type of compounds is mainly distributed in *I. merrillianum*. According to literature review, around 17 monomeric compounds of this type have been isolated so far.

2.3. C_4-C_{11} esterification

This type of compounds from a γ-lactone ring between C_4-C_{11}, and some compounds also exhibit a keto-enol equilibrium between C_7-C_{14} (Fig. 8). They are distributed in plants such as *I. merrillianum* and *I. jiadifengpi*. According to literature review, approximately 10 monomeric compounds of this type have been isolated so far.

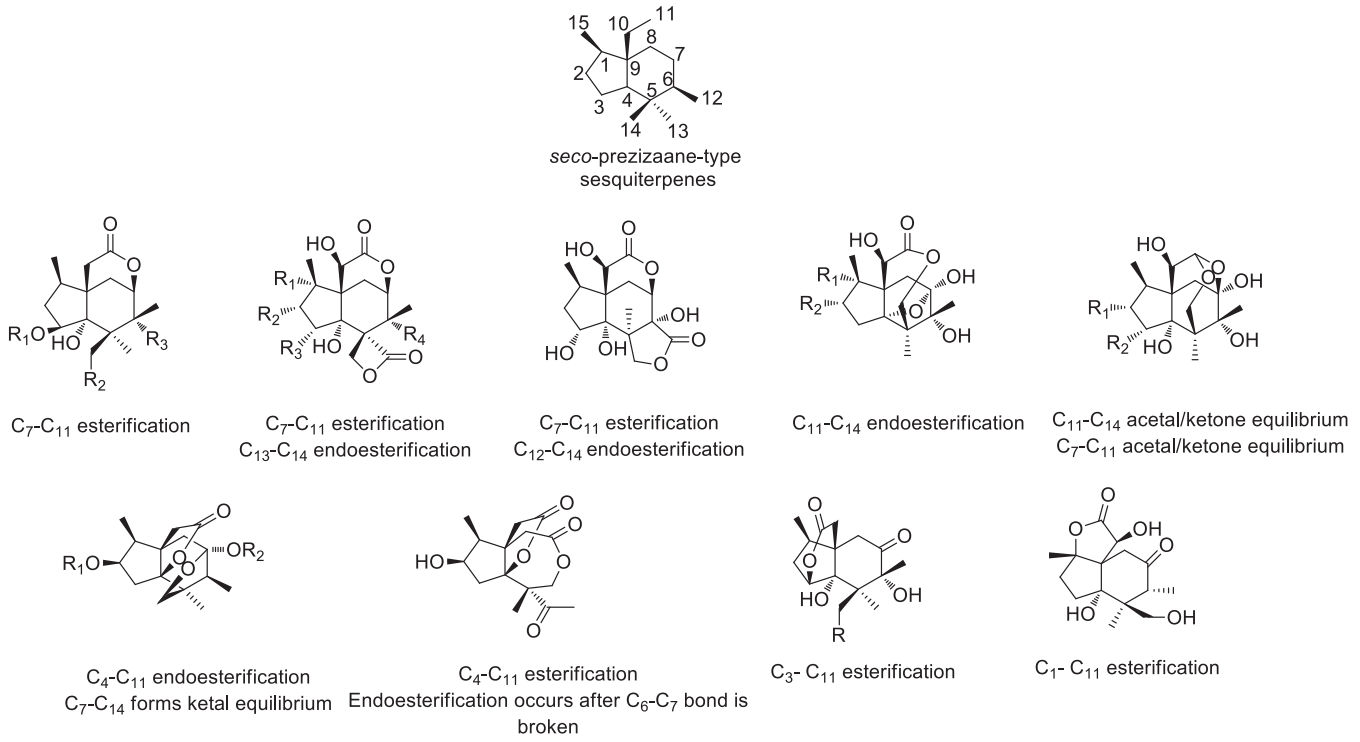


Fig. 2. Seco-prezizaane-type sesquiterpenes classification.

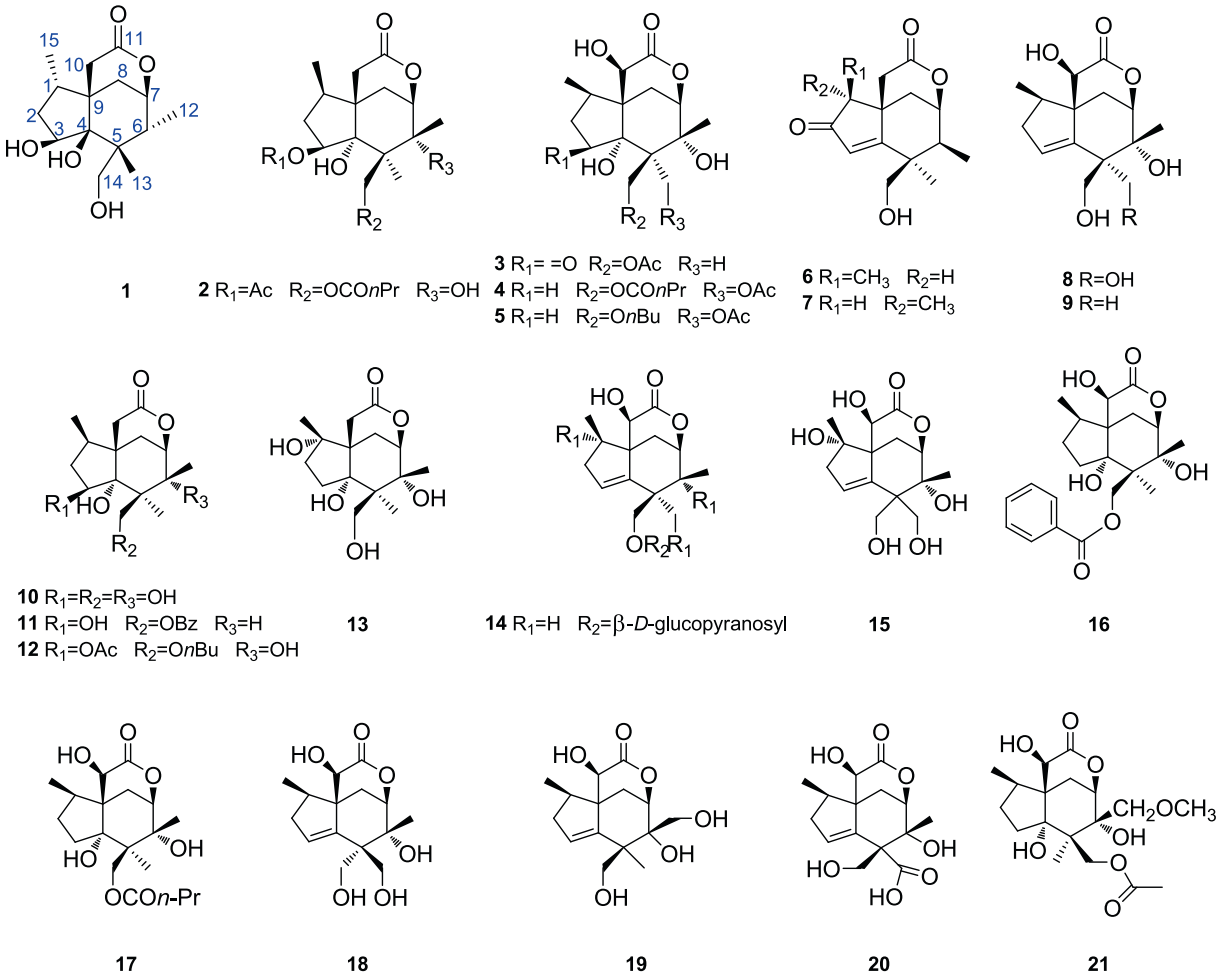
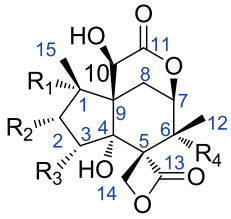
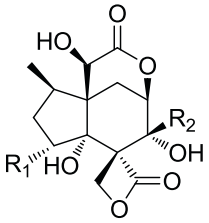


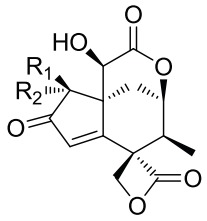
Fig. 3. C_7-C_{11} esterification.



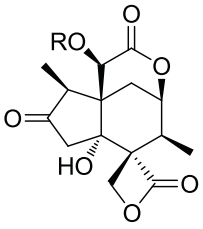
22 R_1=R_2=H R_3=R_4=OH
23 R_1=R_4=OH R_2=R_3=H
24 R_1=OH R_2=R_3=R_4=H
25 R_1=R_3=H R_2=R_4=OH
26 R_1=H R_2=R_3=R_4=OH
27 R_1=R_2=R_3=H R_4=OH



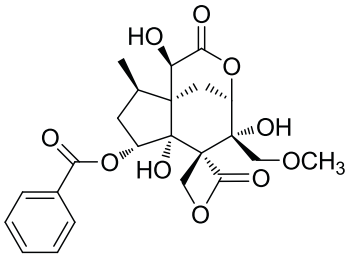
28 R_1=H R_2=CH_2OCH_3
29 R_1=H R_2=CO_2CH_3
30 R_1=OH R_2=CO_2CH_3



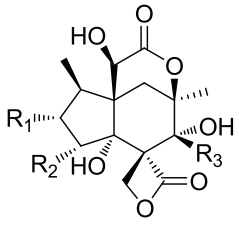
31 R_1=CH_3 R_2=OH
32 R_1=H R_2=CH_3
33 R_1=CH_3 R_2=H



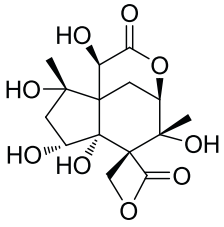
34 R=H
35 R=COCH=CHC_6H_5(*E*)
36 R=COCH=CHC_6H_5(*Z*)



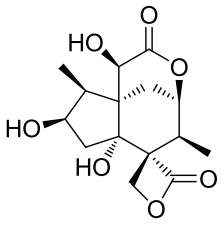
37



38 R_1=H R_2=OH R_3=CH_2OCH_3
39 R_1=OH R_2=H R_3=$COOCH_3$

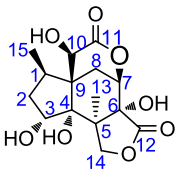


40

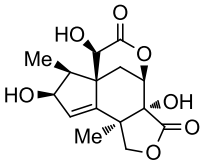


41

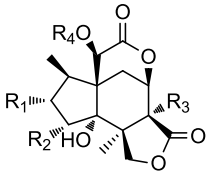
Fig. 4. C_{13}-C_{14} esterification.



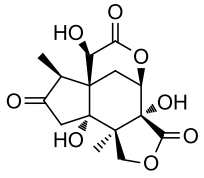
42



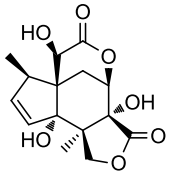
43



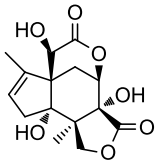
44 R_1=R_2=H R_3=OH R_4=H
45 R_1=R_3=OH R_2=H R_4=H
46 R_1=R_3=H R_2=OH R_4=H
47 R_1=R_2=R_3=H R_4=Bz



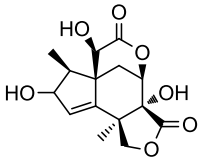
48



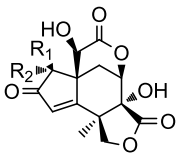
49



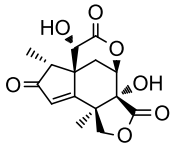
50



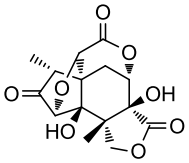
51



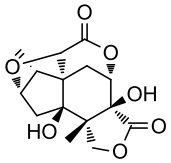
52 R_1=CH_3 R_2=H
53 R_1=H R_2=CH_3



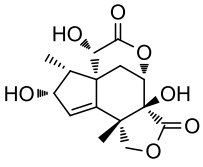
54



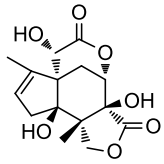
55



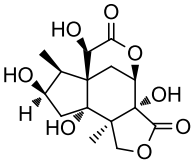
56



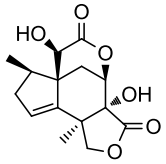
57



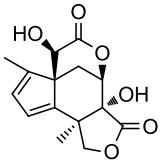
58



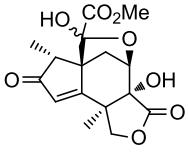
59



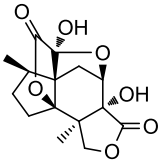
60



61



62



63

Fig. 5. C_{12}-C_{14} esterification.

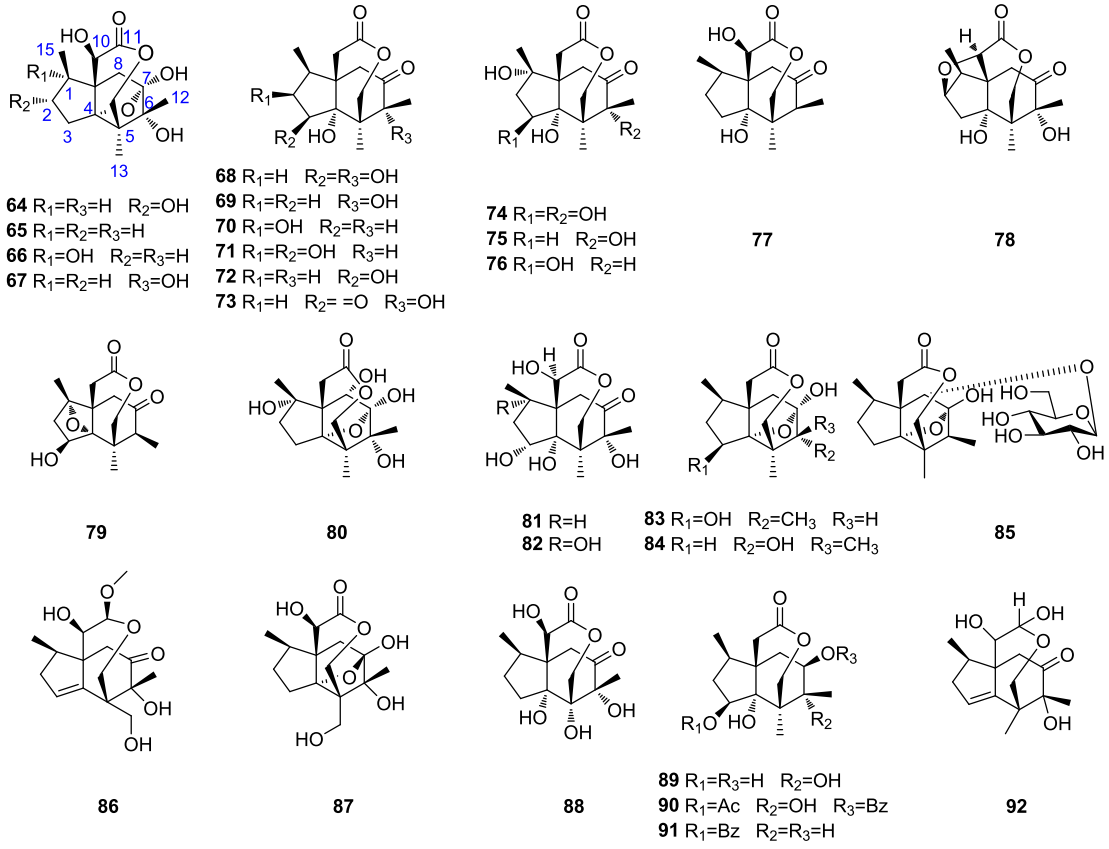


Fig. 6. C_{11}-C_{14} esterification.

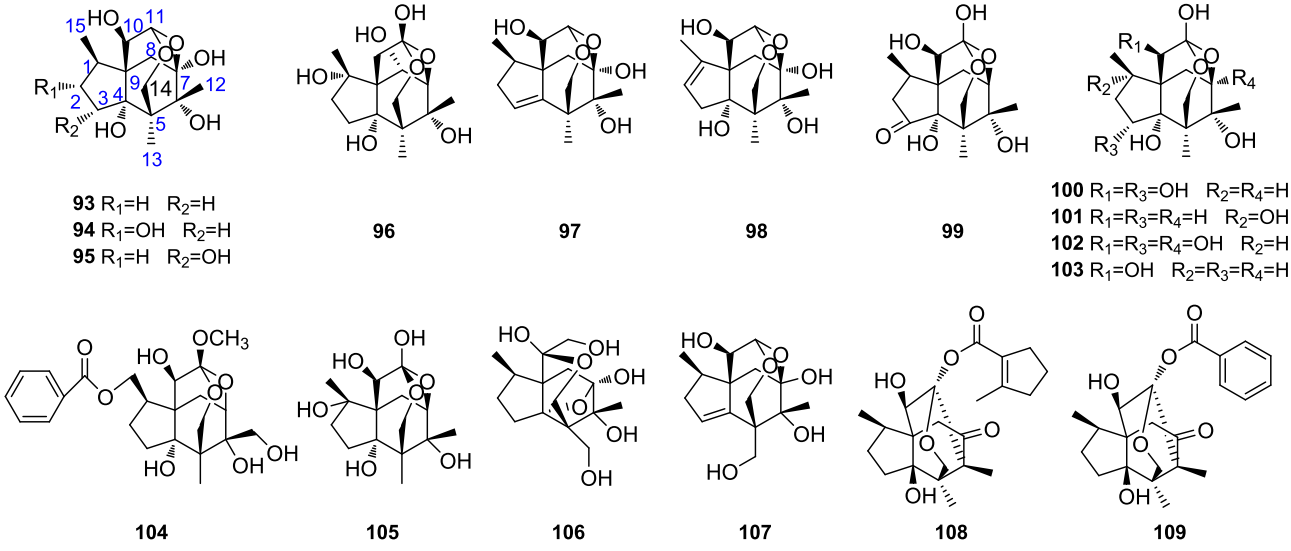


Fig. 7. Acetal-hemiacetal and/or ortholactone.

C_6-C_7 bond rupture: It should be noted that this class of compounds is formed by the esterification reaction between C_4-C_{11}, followed by the cleavage of C_6-C_7 bond and further esterification reaction (Fig. 9). Currently, there are limited reports on the isolation of these compounds from *Illicium* plants.

2.4. C_3-C_{11} esterification

This class of compounds is formed by the esterification reaction between C_3-C_{11} (Fig. 10), and currently, there are limited reports on the isolation of these compounds from *Illicium* plants.

2.5. C_1-C_{11} esterification

This class of compounds is formed by the esterification reaction between C_1-C_{11} (Fig. 11), and currently, there are limited reports on the isolation of these compounds from *Illicium* plants.

The above information provides an overview of the structures of these compounds. Consequently, we have compiled their names, associated activities, and sources in Table 1.

SPS are complex polycyclic sesquiterpenes that are highly oxidized and formed via a series of structural transformations, including cleavage and rearrangement of the prezizaane scaffold

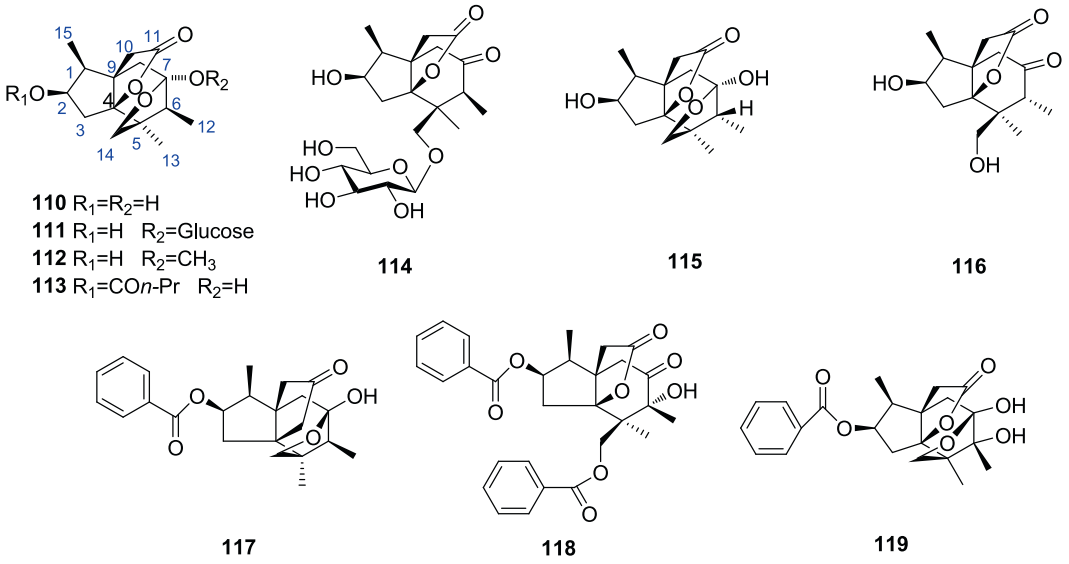


Fig. 8. C_4-C_{11} esterification.

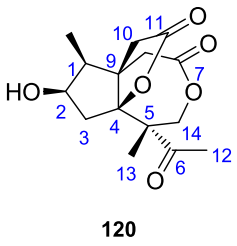


Fig. 9. C_6-C_7 bond rupture.

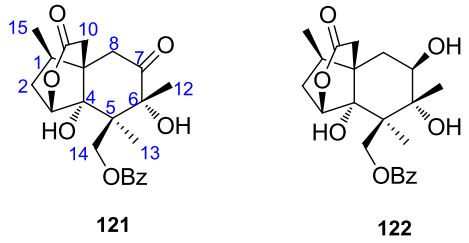


Fig. 10. C_3-C_{11} esterification.

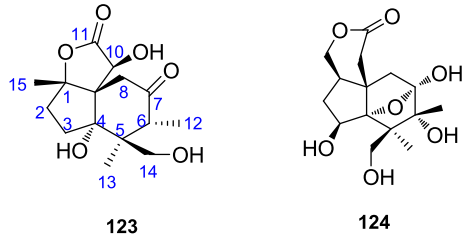


Fig. 11. C_1-C_{11} esterification.

between C_7 and C_{11} positions, as well as additional modifications such as oxidation, esterification, condensation, and dehydration. By reviewing the SPS, we can establish the structural relationship between these compounds (Fig. 12), which may serve as a theoretical basis for future studies on the structure–activity relationship and synthetic applications of SPS.

3. Pharmacological characteristics

3.1. Neuroprotective activity

Neurotrophic factors are important regulatory substances in the nervous system and a subset of biologically active proteins, which are involved in the survival of developing neurons and in the maintenance of mature neurons throughout life. Taking nerve growth factor (NGF) promoting neurite outgrowth and maintaining cell viability as an example, the role of neurotrophic factors in the course of neuronal development has been well understood. Xia et al. showed that the addition of rat NGF in the treatment of Parkinson's disease could significantly increase the level of neurotrophic factor, promote the repair of nerve injury and improve clinical symptoms (Xia, Yuan, & Zhang, 2021). These findings, therefore, offer a hope that NGF may be used as a drug therapy for neurodegenerative diseases such as Parkinson's disease and Alzheimer's disease (Kubo et al., 2009; Wang, Hu, Huang, & Qin, 2011).

Fukuyama et al. found that isodunnianin (**90**) enhanced neurite sprouting during the development of neurons in a primary culture of fetal rat cerebral hemisphere at 10^{-5} mol/L and also increased choline acetyltransferase activity (243 ± 20 pmol/min/mg protein) at 10^{-5} mol/L in comparison with a control culture containing 0.5% ethanol (EtOH) (150 ± 8 pmol/min/mg protein) at 10 d after seeding (Fukuyama, Shida, & Kodama, 1993). Liu et al. evaluated the neuroprotective effect of 1,3-dihydroxyneoanisatin (**40**), and the study results showed a protective rate of 19.9% at 10 μmol/L (Liu et al., 2020). Kubo et al. found that jiadifenolide (**63**) strongly promoted neurite outgrowth in primary cultured rat cortical neurons at concentrations ranging from 0.01 to 10 μmol/L (Kubo et al., 2009).

Therefore, these SPS are expected to be the leading non-peptide neurotrophic agents for the treatment of neurodegenerative diseases such as Alzheimer's disease and Parkinson's disease.

3.2. Anti-inflammatory activity

Some of the sesquiterpene lactones isolated from the genus *Illicium* are considered as responsible for the neurotoxicity of these plants. Such as anisatin (**22**) with a β-lactone structure acts as a picrotoxin-like, non-competitive γ-aminobutyric acid (GABA)

Table 1
Seco-prezizaane-type sesquiterpenes found in *Illicium* plants.

No.	Compounds	Activities	Source	References
1	Minwanensin		*I. minwanense*	Fukuyama & Huang, 2005
2	3-Acetoxy-14-*n*-butyryloxy-10-deoxyfloridanolide		*I. floridanum*	Fukuyama & Huang, 2005
3	14-Acetoxy-3-oxofloridanolide		*I. floridanum*	Fukuyama & Huang, 2005
4	13-Acetoxy-14-butyryloxyfloridanolide		*I. floridanum*	Huang, Yang, Takahashi, & Fukuyama, 2000
5	13-Acetoxy-14-(*n*-butyryloxy) floridanolide		*I. floridanum*	Schmidt, Schmidt, Müller, Peters, & Fischer, 1998
6	(1*S*)-Minwanenone	Cytotoxicity	*I. minwanense*	Fukuyama & Huang, 2005
7	(1*R*)-Minwanenone		*I. minwanense*	Fukuyama & Huang, 2005
8	3,4-Dehydro-13,14-dihydroxyfloridanolide		*I. floridanum*	Fukuyama & Huang, 2005
9	3,4-Dehydrofloridanolide		*I. merrillianum*	Huang, Yang, Takahashi, & Fukuyama, 2000
10	3β,14-Dihydroxy-10-deoxyfloridanolide		*I. floridanum*	Schmidt, Okuyama, & Fronczek, 1999
11	14-*O*-Benzoylfloridanolide	Cytotoxicity	*I. dunnianum*	Yadav, Mondal, & Ghosh, 2011
12	3β-Acetoxy-14-*n*-butyryloxy-10-deoxyfloridanolide		*I. floridanum*	Schmidt, Schmidt, Müller, Peters, & Fischer, 1998
13	1,6-Dihydroxy-3-deoxyminwanensin		*I. merrillianum*	Huang, Yang, Zhao, Takahashi, & Fukuyama, 2004
14	Dunnianolide A		*I. dunnianum*	Bai et al., 2012
15	Dunnianolide B		*I. dunnianum*	Bai et al., 2012
16	2-*O*-Benzoylfloridanolide		*I. dunnianum*	Bai et al., 2012
17	14-*O*-*n*-Butyrylfloridanolide		*I. merrillianum*	Huang, Yang, Takahashi, & Fukuyama, 2000
18	3,4-Anhydro-13,14-dihydroxyfloridanolide		*I. floridanum*	Schmidt, Müller, & Fronczek, 2001
19	(1*R*,5*R*,6*S*,7*R*,9*R*,10*R*)-3,4-Dehydro-12-hydroxy-floridanolide	Neuroprotection	*I. lanceolatum*	Liu et al., 2020
20	3,4-Dehydrofloridanolide-13-oic-acid		*I. lanceolatum*	Liu et al., 2020
21	Burmanicumolide D		*I. ternstroemioides*	Zhang, Li, Yong, Yang, & Ma, 2021
22	Anisatin	Neurotoxicity	*I. anisatum*	Huang et al., 2002b
23	1-Hydroxyneoanisatin	Neuroprotection	*I. majus*	Fukuyama & Huang, 2005
24	6-Deoxy-1-hydroxyneoanisatin		*I. majus*	Fukuyama & Huang, 2005
25	2α-Hydroxyneoanisatin	Neurotoxicity	*I. anisatum*	Fukuyama & Huang, 2005
26	2α-Hydroxyanisatin		*I. merrillianum*	Fukuyama & Huang, 2005
27	Neoanisatin		*I. dunnianum*	Huang et al., 2002b
28	Veranisatins A	Neurotoxicity	*I. verum*	Fukuyama & Huang, 2005
29	Veranisatins B	Neurotoxicity	*I. verum*	Fukuyama & Huang, 2005
30	Veranisatins C	Neurotoxicity	*I. verum*	Fukuyama & Huang, 2005
31	3,4-Anhydro-2-oxo-1α-hydroxy-6-deoxyneoanisatin		*I. lanceolatum*	Nie et al., 2022
32	3,4-Dehydroxy-6-oxoneoanisatin		*I. majus*	Kouno et al., 1991
33	3,4-Dehydroxy-6-oxoneoanisatin		*I. majus*	Kouno et al., 1991
34	2-Oxo-6-dehydroxyneoanisatin	Neurotoxicity	*I. majus*	Yang et al., 1990
35	10-*O*-(*E*)-Cinnamoyl-2-oxo-6-deoxyneoanisatin		*I. fargesi*	(Moriyama et al., 2008)
36	10-*O*-(*Z*)-Cinnamoyl-2-oxo-6-deoxyneoanisatin		*I. fargesi*	(Moriyama et al., 2008)
37	Veranisatin F		*I. simonsii*	Yin, Wang, Wang, & Kong, 2012
38	Veranisatin D		*I. oligandrum*	Zhu et al., 2009
39	Veranisatin E		*I. oligandrum*	Zhu et al., 2009
40	1,3-Dihydroxyneoanisatin	Neuroprotection	*I. lanceolatum*	Liu et al., 2020
41	2β-Hydroxy-6-deoxyneoanisatin		*I. lanceolatum*	Nie et al., 2022
42	Majucin		*I. jiadifengpi*	Cheng & Micalizio, 2014
43	(2*S*)-Hydroxy-3,4-dehydroneomajucin		*I. jiadifengpi*	Cheng & Micalizio, 2014
44	Neomajucin	Anti-inflammation	*I. angustisepalum*	Fukuyama & Huang, 2005
45	(2*S**)-Hydroxyneomajucin		*I. majus*	Fukuyama & Huang, 2005
46	6-Deoxy-neomajucin		*I. majus*	Fukuyama & Huang, 2005
47	Angustisepalin		*I. majus*	Sy & Brown, 1998
48	2-Oxoneomajucin	Antiviral	*I. jiadifengpi*	Zhang et al., 2013
49	2,3-Dehydromajucin		*I. majus*	Fukuyama & Huang, 2005
50	1,2-Dehydroneomajucin		*I. jiadifengpi*	Fukuyama & Huang, 2005
51	(2*R**)-Hydroxy-3,4-dehydroneomajucin		*I. majus*	Fukuyama & Huang, 2005
52	(1*S**)-2-Oxo-3,4-dehydroneomajucin		*I. majus*	Fukuyama & Huang, 2005
53	(1*R**)-2-Oxo-3,4-dehydroxyneomajucin		*I. majus*	Fukuyama & Huang, 2005
54	(1*R**,10*S**)-2-Oxo-3,4-dehydroneomajucin		*I. majus*	Fukuyama & Huang, 2005
55	Jiadifenoxolane A	Neuroprotection	*I. jiadifengpi*	(Kubo et al., 2009)
56	Jiadifenoxolane B		*I. jiadifengpi*	(Kubo et al., 2009)
57	(2*S*)-Hydroxy-3,4-dehydroneomajucin	Neuroprotection	*I. lanceolatum*	Mehta, Shinde, & Kumaran, 2012
58	Dehydro-neomajucin		*I. verum* Hook.f.	Mehta, Shinde, & Kumaran, 2012
59	(2*R**)-Hydroxyneomajucin		*I. jiadifengpi*	(Kubo et al., 2012)
60	3,4-Dehydroneomajucin	Anti-HBV	*I. jiadifengpi*	Liu et al., 2016
61	1,2,3,4-Tetradehydroneomajucin	Anti-HBV	*I. jiadifengpi*	Liu et al., 2016
62	Jiadifenin		*I. jiadifengpi*	Gomes et al., 2016
63	Jiadifenolide	Neuroprotection	*I. jiadifengpi*	Gomes et al., 2016
64	2α-Hydroxycycloparviflorolide		*I. merrillianum*	(Huang et al., 2002a)
65	Cycloparviflorolide	Neuroprotection	*I. parviflorum*	Huang et al., 2002b
66	Cyclomerrillianolide		*I. merrillianum*	Huang et al., 2002b
67	10β-Hydroxy-cyclopseudoanisatin		*I. merrillianum*	Huang, Yang, Zhao, Takahashi, & Fukuyama, 2004

Table 1 (*continued*)

No.	Compounds	Activities	Source	References
68	Pseudoanisatin		*I. anisatum*	Fukuyama & Huang, 2005
69	3-Deoxypseudoanisatin		*I. merrillianum*	Fukuyama & Huang, 2005
70	2β-Hydroxy-3,6-dedioxypseudoanisatin		*I. merrillianum*	Fukuyama & Huang, 2005
71	(2*S*)-Hydroxy-6-deoxypseudoanisatin		*I. minwanense*	Fukuyama & Huang, 2005
72	6-Deoxypseudoanisatin		*I. anisatum*	Fukuyama & Huang, 2005
73	3-Oxopseudoanisatin		*I. minwanense*	Fukuyama & Huang, 2005
74	1α-Hydroxypseudoanisatin		*I. anisatum*	Fukuyama & Huang, 2005
75	1α-Hydroxy-3-deoxypseudoanisatin		*I. merrillianum*	Fukuyama & Huang, 2005
76	1α-Hydroxy-6-deoxypseudoanisatin		*I. minwanense*	Fukuyama & Huang, 2005
77	3,6-Dideoxy-10-hydroxy-pseudoanisatin		*I. merrillianum*	Fukuyama & Huang, 2005
78	2,10-Epxoy-3-dehydroxypseudoanisatin		*I. merrillianum*	Fukuyama & Huang, 2005
79	1,4-Epoxy-6-deoxypseudoanisatin		*I. dunnianum*	Fukuyama & Huang, 2005
80	8α-Hydroxy-10-deoxycyclomerrillianolide		*I. merrillianum*	Huang, Yang, Zhao, Takahashi, & Fukuyama, 2004
81	10β-Hydroxypseudoanisatin		*I. merrillianum*	Huang, Yang, Zhao, Takahashi, & Fukuyama, 2004
82	Merrillianolide		*I. merrillianum*	Huang, Yang, Zhao, Takahashi, & Fukuyama, 2004
83	(3S*,6R*)-4,7-Epoxy-6-deoxypseudoanisatin		*I. minwanense*	Yokoyama et al., 2003
84	4,7-Hemiketal of pseudoanisatin		*I. parviflorum*	Schmidt, 1999
85	8-*O*-β-*D*-Glucopyranosyl-8α-hydroxy-6,10-dideoxy-cycloparviflorolide		*I. jiadifengpi*	Zhang et al., 2013
86	Illilanceolatin B		*I. lanceolatum*	Liu et al., 2020
87	Majusanol E	Neuroprotection	*I. lanceolatum*	Liu et al., 2020
88	Parviflorohde		*I. parviflorum*	Fukuyama & Huang, 2005
89	7-Deoxy-7β-hydroxypseudoanisatin		*I. anisatum*	Fukuyama & Huang, 2005
90	Isodunnianin	Neuroprotection	*I. merrillianum*	Fukuyama & Huang, 2005
91	6-Deoxydunnianin		*I. anisatum*	Fukuyama & Huang, 2005
92	Majusatone		*I. majus*	Fang, Zhang, & Liu, 2016
93	Cycloparvifloralone		*I. parviflorum*	Huang et al., 2002b
94	2α-Hydroxycycloparvifloralone		*I. merrillianum*	Huang et al., 2002a
95	3α-Hydroxycycloparvifloralone	Neuroprotection	*I. merrillianum*	Fukuyama & Huang, 2005
96	Merrilliortholactone		*I. merrillianum*	Huang et al., 2002a
97	Merrillianone		*I. merrillianum*	Fukuyama & Huang, 2005
98	1,2-Dehydrocycloparvifloralone		*I. merrillianum*	Fukuyama & Huang, 2005
99	(11)7,14-Ortholactone-14-hydroxy-3-oxofloridanolide		*I. floridanum*	Fukuyama & Huang, 2005
100	(11)7,14-Ortholctone-3α-hydroxyfloridanolide	Neuroprotection	*I. merrillianum*	Fukuyama & Huang, 2005
101	8-Deoxymerrilliortholactone		*I. merrillianum*	Huang, Yang, Zhao, Takahashi, & Fukuyama, 2004
102	7,14-Ortholactone-3α-hydroxy-floridanolide		*I. merrillianum*	Huang, Yang, Takahashi, & Fukuyama, 2000
103	Henrylactone C	Neuroprotection	*I. lanceolatum*	Liu et al., 2019
104	Oligandriortholactone	Anti-inflammation	*I. oligandrum*	Tang et al., 2009
105	(11)7,14-Ortholactone-1α-hydroxyfloridanolide		*I. jiadifengpi*	Zhang et al., 2013
106	Illilanceolatin A		*I. lanceolatum*	Liu et al., 2020
107	Majusanol A	Neuroprotection	*I. lanceolatum*	Liu et al., 2019
108	11-*O*-Debenzoyl-11α-*O*-2-methylcyclopent-1-Enecarboxyltashironin		*I. verum*	Wang, Hu, Huang, & Qin, 2011
109	Tashironin		*I. verum*	Wang, Hu, Huang, & Qin, 2011
110	Pseudomajucin		*I. majus*	Fukuyama & Huang, 2005
111	7-*O*-β-*D*-Glucoside pseudomajucin		*I. majus*	Fukuyama & Huang, 2005
112	7-*O*-Methylpseudomajucin		*I. minwanense*	Yokoyama et al., 2003
113	2-*O*-*n*-Butyrylpseudomajucin		*I. merrillianum*	Huang, Yang, Takahashi, & Fukuyama, 2000
114	14-*O*-β-*D*-Glucopyranosylpseudomajucinone	Antiviral	*I. jiadifengpi*	Zhang et al., 2013
115	(6*R*)-Pseudomajucin		*I. merrillianum*	Fukuyama & Huang, 2005
116	(6*R*)-Pseudomajucinone		*I. merrillianum*	Fukuyama & Huang, 2005
117	Dunnianolide C		*I. dunnianum*	Bai et al., 2012
118	Dunnianolide D		*I. dunnianum*	Bai et al., 2012
119	2β-Benzoyloxy-6α-hydroxypseudomajucin		*I. jiadifengpi*	Zhang et al., 2013
120	Merrillianin		*I. merrillianum*	Huang et al., 2002b
121	7-Deoxy-7-oxodunnianin		*I. foridanum*	Schmidt, Okuyama, & Fronczek, 1999
122	Dunnianin		*I. dunnianum*	Schmidt, Gurrath, & Ozoe, 2004
123	Illilanceolide A		*I. lanceolatum*	Nie, Ding, Lei, Pan, & Zhao, 2021
124	Neodunnianin		*I. dunnianum*	Fukuyama & Huang, 2005

antagonist. However, some sesquiterpenes were found not to be neurotoxic but to have neurotrophic activities. These properties can affect the effectiveness of the active sesquiterpene lactones as potential anti-inflammatory agents (Bai et al., 2012).

Tang et al. evaluated the anti-inflammatory activities of the compounds by measuring the inhibitory ratios of β-glucuronidase release in rat polymorphonuclear leukocytes (PMNs) induced by platelet-activating factor (PAF) *in vitro*. These suggested that the compounds oligandriortholactone (**104**) and neomajucin (**44**) showed weak inhibitory activities of β-glucuronidase release from rat PMNs induced by PAF (Tang et al., 2009). Bai et al. isolated and identified tashironin (**109**) from the roots of *Illicium dunnianum* and evaluated its anti-inflammatory activity. The results showed that tashironin exhibited significant anti-inflammatory activity

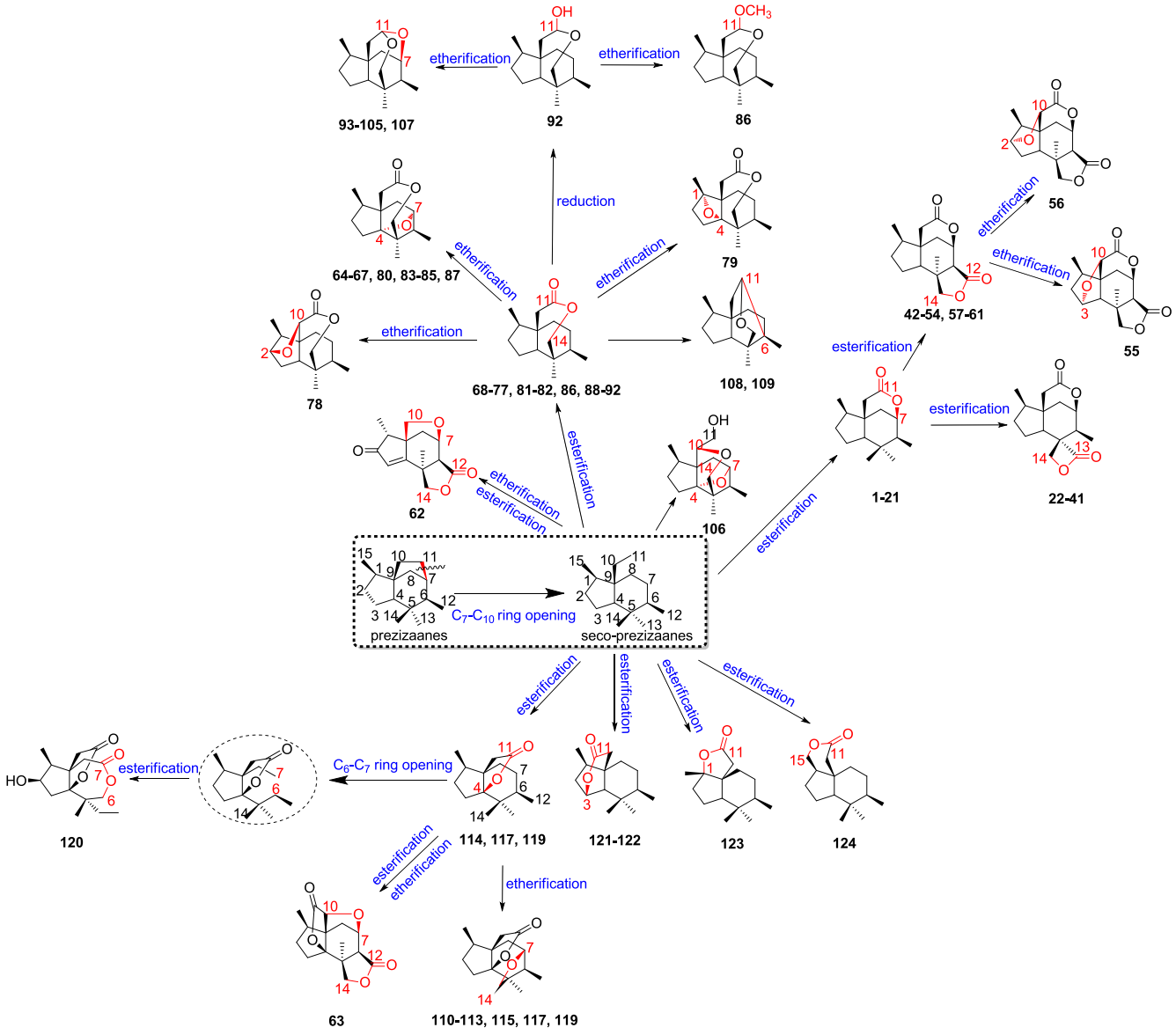


Fig. 12. Possible biosynthetic pathways of seco-prezizaane-type sesquiterpenes.

with IC_{50} values of (2.10 ± 0.40) μmol/L and (1.93 ± 0.57) μmol/L (Bai et al., 2012). Therefore, SPS has the potential to be developed as an anti-inflammatory agent.

3.3. Calm, analgesic and convulsive activities

Nakamura et al. reported that veranisatins (A-C) (**28**–**30**) exhibited convulsive and lethal toxicity in mice at a dose of 3 mg/kg (p. o.), and at lower doses, they induced hypothermia. Veranisatin A (**28**) and its related compound, anisatin (**22**), were also evaluated for other pharmacological activities, including locomotor activity and analgesic effects. Both compounds reduced locomotion enhanced by methamphetamine at oral doses of 0.1 and 0.03 mg/kg, respectively. Additionally, they demonstrated analgesic effects on acetic acid-induced writhing and tail pressure pain at doses that were almost identical (Nakamura, Okuyama, & Yamazaki, 1996).

Okuyama et al. showed that veranisatin A and B (28, 29) exhibited convulsive effects and lethal toxicity at a dose of 3 mg/kg, (p. o.), while at 1 mg/kg, both compounds induced hypothermia (ΔT_{max} 4.5 ℃, P < 0.001) but no convulsions (Okuyama, Nakamura, & Yamazaki, 1993). Therefore, these compounds may be used as analgesic and sedative drugs.

3.4. Antiviral activity

Zhang et al. evaluated the antiviral activity of 14-*O*-*β*-*D*-gluco pyranosylpseudomajucinone (**114**) by measuring the *in vitro* activity against Coxsackie virus B3 (Li et al., 2010). They found that the compound had certain inhibitory activity against Coxsackie virus B3, with IC_{50} value of 40.50 μmol/mL (the positive control, ribavirin, IC_{50} = 1.25 μmol/mL) (Zhang et al., 2013).

3.5. Other activities

Liu et al. evaluated the anti-HBV activity of 3,4-dehydroneomajucin (**60**) and 1,2,3,4-tetradehydroneomajucin (**61**) in HBV-transfected HepG 2.2.15 cell line at non-cytotoxic con-

centration with amivudine (3TC) as a positive control. They found that the inhibitory rates of compounds 3,4-dehydrooneomajucin and 1,2,3,4-tetradehydrooneomajucin on the Hepatitis B e antigen (HBeAg) and Hepatitis B surface antigen (HBsAg) expression were (30.08 ± 3.09)% and (11.43 ± 1.92)% at a concentration of 68.00 μmol/L, and (7.88 ± 1.21)% and (16.96 ± 4.24)% at a concentration of 68.50 μmol/L, respectively. The results revealed that the anti-HBV activities of the tested compounds were weak in the measured concentration range (Liu et al., 2016).

Fang et al. used MTT method to study the cytotoxicity of majusatone (**92**). The results showed that the IC_{50} values of majusatone on human colon cancer cell HCT-8, human liver cancer cell BEL-7402, human gastric cancer cell BGC-823, and human lung cancer cell A549 were 42.3, 48.5, 51.1, and 39.9 μmol/L, respectively. It means that they have no obvious cytotoxicity (Fang, Zhang, & Liu, 2016).

4. Toxicity

4.1. Neurotoxicity

Fukuyama et al. reported that anisatin (**22**) and neoanisatin (**27**) were convulsive toxic components of *I. anisatum* and regarded as picrotoxin-like potent phytotoxins (Fukuyama & Huang, 2005). Neuropharmacological study demonstrates that the convulsive toxicity of anisatin may be due to its function as a picrotoxin-like, non-competititve GABA-antagonist (Kudo, Oka, & Yamada, 1981). But at the present, which structural part of anisatin is of significance to cause convulsive activity is equivocal. Among anisatin related compounds, veranisatins A, B and C (**28**–**30**) isolated from non-toxic chinese star anise (*I. vernum*) caused convulsions and death at 3 mg/kg (p.o.) in mice, whereas 2α-hydroxyneoanisatin (**25**), a positional isomer of the potent neurotoxic anisatin, induced no anisatin/picrotoxin-like convulsions and dramatically decreased the neurotoxicity in mice in comparison with anisatin and neoanisatin (Fukuyama & Huang, 2005). Therefore, it is speculated that the presence of β-lactone may be the cause of neurotoxicity, but it is not the absolute cause.

4.2. Insecticidal activity

Insects possess GABA receptors that are similar but exhibit pharmacological differences, not only in their central nervous system but also in their peripheral nervous system (Anthony, Unruh, Ganser, & Ffrench-Constant, 1998). Some SPS, such as anisatin, have been identified as non-competitive antagonists (NCAs) of GABA receptors (Kuriyama, Schmidt, Okuyama, & Ozoe, 2002). NCAs can block the chloride channel of nerve cells by interacting with the amino acid residues of GABA-gated chloride channel (GABA-Cl), causing changes in receptor conformation, thereby interfering with the normal function of the central nervous system. This causes excessive excitation of nerves and muscles, eventually leading to the death of insects (Liu et al., 2022). Kuriyama et al. studied the insecticidal activity of anisatin and pseudoanisatin (**68**) by injecting them into German cockroaches (*Blattella germanica* L.), which was topically pretreated with cytochrome P450 or piperonyl butoxide to depress the oxidative metabolism of the compounds. They found that pseudoanisatin and anisatin exhibited a similar level of insecticidal activity, with LD_{50} of 26 and 70 mg/g, respectively (Kuriyama, Schmidt, Okuyama, & Ozoe, 2002). The insecticidal activity of anisatin and pseudoanisatin on German cockroaches was moderate (Wang, Hu, Huang, & Qin, 2011). Therefore, these compounds may be used as probes for GABA receptors or lead compounds with insecticidal activity.

4.3. Cytotoxicity

Yin et al. evaluated anisatin and (1*S*)-minwanenone (**6**) for cytotoxic activity by the MTT method in 96-well microplates, using two human cancer cell lines NCI-H460 (human large cell lung cancer cell line) and SMMC-7721 (human hepato-cellular carcinoma cell line), with 5-fluorouracil (5-FU) as a positive control. They found that the potent inhibitory effects of anisatin and (1*S*)-minwanenone (**6**) on NCI-H460 and SMMC-7721 cells were comparable to that of 5-FU (Yin, Wang, Wang, & Kong, 2012).

5. Conclusion

Changes in the structure of the lactone rings in SPS, such as the formation of 11,14-ε-lactone or 11,3-δ-lactone or mutation of 13,14-β-lactone to 13-methyl-14-hydroxy or -*O*-acyl substituents, lead to a complete loss of the activity (Schmidt, Okuyama, & Fronczek, 1999). When anisatin undergoes hydroxy transfer, it forms 2α-hydroxyneoanisatin, which is still active, but its potency is 53 times lower than that of anisatin. The substitution of the β-lactone ring and the bulk group at the C_5 position are somewhat admissible, while the acetylation of the C_3 hydroxy group is deleterious. Similarly, the analogues in different cyclysis modes (lack of a closed lactone ring between C_{11} and C_7) have little activity (Kuriyama, Schmidt, Okuyama, & Ozoe, 2002).

From the above summary, it is not difficult to find that the C ring is more easily to cleaved and combined with other sites. The activity of a compound can differ if its method of binding to other sites is different, and there will also be a lower probability of ring opening of the AB ring. Although a few of these compounds were isolated, it is impossible to judge whether the ring opening of the AB-ring will affect the activity of the compounds. When there is present a 13,14-β-lactone, most of the neurotoxic compounds show no toxicity and neurotrophic activity after β-lactone ring opening. When there is 11,14-lactone, the compounds have nerve protective effect, while in the presence of γ-lactone some compounds showed anti-inflammatory and antiviral activity. At the same time, when there is no hydroxy at the C_{10} position, the compounds have almost no activity. Sesquiterpenes belong to a complex class of compounds, so it is difficult to separate them. However, we may modify the structures of sesquiterpenes by a series of reactions such as esterification and oxidation, so as to obtain the compounds with a higher activity.

CRediT authorship contribution statement

Ye Jin: Data curation, Formal analysis, Visualization, Writing – original draft. **Yanqing Xie:** Writing – review & editing. **Peng Zhang:** . **Afsar Khan:** Supervision, Writing – review & editing. **Zhihong Zhou:** Supervision, Writing – review & editing. **Lu Liu:** Conceptualization, Data curation, Project administration, Validation, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

This work was financially supported by Yunnan Provincial Science and Technology Department-Applied Basic Research Joint Special Funds of Chinese Medicine (No. 202101AZ070001-004); Major Science and Technology Special Project from Yunnan Provincial Science and Technology Department (No. 202202AA100009, 202302AA310006); Universities Engineering Research Center of Yunnan Province (No. 2020YGG01), and Open and Shared Public Science and Technology Service Platform of Traditional Chinese Medicine Science and Technology Resources in Yunnan.

References

Anthony, N., Unruh, T., Ganser, D., & Ffrench-Constant, R. (1998). Duplication of the Rdl GABA receptor subunit gene in an insecticide-resistant aphid, Myzus persicae. *Molecular and General Genetics MGG, 260*(2), 165–175.

Bai, J., Chen, H., Fang, Z. F., Yu, S. S., Wang, W. J., Yang, L., ... Song, X. (2012). Sesquiterpenes from the roots of *Illicium dunnianum*. *Phytochemistry, 80*, 137–147.

Cheng, X. Y., & Micalizio, G. C. (2014). An annulation reaction for the synthesis of cross-conjugated triene-containing hydroindanes from acyclic precursors. *Organic Letters, 16*(19), 5144–5147.

Fang, Z. F., Zhang, L., & Liu, X. (2016). A new *seco*-prezizaane-type sesquiterpenoid from twigs and leaves of *Lliciuim majus*. *Chinese Traditional and Herbal Drugs, 47*(16), 2803–2805.

Fukuyama, Y., & Huang, J. M. (2005). Chemistry and neurotrophic activity of *seco*-prezizaane-and anislactone-type sesquiterpenes from *Illicium* sfecies. *Studies in Natural Products Chemistry, 32*(5), 395–427.

Fukuyama, Y., Shida, N., & Kodama, M. (1993). Isodunnianin: A new sesquiterpene enhancing neurite outgrowth in primary culture of fetal rat cerebral hemisphere from *Illicium tashiroi*. *Planta Medica, 59*(2), 181–182.

Gomes, J., Daeppen, C., Liffert, R., Roesslein, J., Kaufmann, E., Heikinheimo, A., ... Gademann, K. (2016). Formal total synthesis of (−)-jiadifenolide and synthetic studies toward *seco*-prezizaane-type sesquiterpenes. *The Journal of Organic Chemistry, 81*(22), 11017–11034.

Huang, J. M., Nakade, K., Kondo, M., Yang, C. S., & Fukuyama, Y. (2002a). Brine shrimp lethality test active constituents and new highly oxygenated *seco*-prezizaane-type sesquiterpenes from *Illicium merrillianum*. *Chemical & Pharmaceutical Bulletin, 50*(1), 133–136.

Huang, J. M., Yang, C. S., Kondo, M., Nakade, K., & Fukuyama, Y. (2002b). Merrillianin, a unique seco-prezizaane-type sesquiterpene, and (6R)-pseudomajucin from Illicium merrillianum. *Tetrahedron, 58*(34), 6937–6941.

Huang, J. M., Yang, C. S., Takahashi, H., & Fukuyama, Y. (2000). *Seco*-prezizaane-type sesquiterpenes from *Illicium merrillianum*. *Phytochemistry, 55*(8), 883–886.

Huang, J. M., Yang, C. S., Zhao, R., Takahashi, H., & Fukuyama, Y. (2004). Seven novel seco-prezizaane-type sesquiterpenes from the pericarps of *Illicium merrillianum*. *Chemical & Pharmaceutical Bulletin, 52*(1), 104–107.

Kawamura, T., Moriya, H., Shibuya, M., & Yamamoto, Y. (2019). Diastereoselective methylation at the congested β-position of a butenolide ring: Studies toward the synthesis of *seco*-prezizaane-type sesquiterpenes. *The Journal of Organic Chemistry, 84*(19), 12508–12519.

Kouno, I., Hashimoto, M., Enjoji, S., Takahashi, M., Kaneto, H., & Yang, C. S. (1991). Isolation of neoanisatin derivatives from the pericarps of *Illicium majus* with other constituents. *Chemical and Pharmaceutical Bulletin, 39*(7), 1773–1778.

Kubo, M., Okada, C., Huang, J. M., Harada, K., Hioki, H., & Fukuyama, Y. (2009). Novel pentacyclic *seco*-prezizaane-type sesquiterpenoids with neurotrophic properties from *Illicium jiadifengpi*. *Organic Letters, 11*(22), 5190–5193.

Kubo, M., Kobayashi, K., Huang, J. M., Harada, K., & Fukuyama, Y. (2012). The first examples of *seco*-prezizaane-type norsesquiterpenoids with neurotrophic activity from *Illicium jiadifengpi*. *Tetrahedron Letters, 53*(10), 1231–1235.

Kudo, Y., Oka, J. I., & Yamada, K. (1981). Anisatin, a potent GABA antagonist, isolated from *Illicium anisatum*. *Neuroscience letters, 25*(1), 83.

Kuriyama, T., Schmidt, T. J., Okuyama, E., & Ozoe, Y. (2002). Structure-activity relationships of *seco*-prezizaane terpenoids in γ-aminobutyric acid receptors of houseflies and rats. *Bioorganic & Medicinal Chemistry, 10*(6), 1873–1881.

Li, L. B., Shen, Y., & Zhang, Y. D. (2016). Synthetic progress of Jiadifenolide. *Chinese Journal of Organic Chemistry, 36*(3), 439.

Li, Y. P., Shan, G. Z., Peng, Z. G., Zhu, J. H., Meng, S., Zhang, T., ... Li, Y. H. (2010). Synthesis and biological evaluation of heat-shock protein 90 inhibitors: Geldanamycin derivatives with broad antiviral activities. *Antiviral Chemistry & Chemotherapy, 20*(6), 259–268.

Liu, D. D., Zhu, C., Wang, F., Gao, Y. X., Zhang, J., & Zhang, L. X. (2022). Research progress of Insecticide acting on γ-aminobutyric acid receptors. *Chemical Reagent, 44*(1), 21–31.

Liu, J. F., Li, Y. C., Wang, L., Wang, Y. F., Jia, L., Bi, Y. F., & Zhang, Y. B. (2014). Jiadifenlactone A, a novel diseco-prezizaane-type sesquiterpenoid from the fruits of *Illicium jiadifengpi*. *Tetrahedron Letters, 55*(18), 2942–2944.

Liu, J. F., Liu, F. Y., Zhang, N. L., Wang, Y. F., Yang, L. J., Bi, Y. F., ... Liu, M. Q. (2016). Two new sesquiterpene lactones from the fruits of *Illicium jiadifengpi*. *Natural Product Research, 30*(3), 322–326.

Liu, Y. L., Li, W. R., Zhang, J. P., Yong, J. Y., Zhang, D., & Ma, S. G. (2019). Investigation on *seco*-prezizaane sesquiterpenes from fruits of *Illicium lanceolatum* and their neuroprotection activity. *China Journal of Chinese Materia Medica, 44*(19), 4207–4211.

Liu, Y. L., Li, W. R., Wang, X. J., Wang, R. B., Li, M., Zhang, J. P., ... Ma, S. G. (2020). Highly oxidized sesquiterpenes from the fruits of *Illicium lanceolatum* A. C. Smith. *Phytochemistry, 172*, 112281.

Mehta, G., Shinde, H. M., & Kumaran, R. S. (2012). Model synthetic studies toward *jiadifenin* and *majucin* type *seco*-prezizaane natural products via a stereo-and enantioselective approach. *Tetrahedron Letters, 53*(33), 4320–4323.

Moriyama, M., Huang, J. M., Yang, C. S., Kubo, M., Harada, K., Hioki, H., & Fukuyama, Y. (2008). Two new sesquiterpenoids and two new prenylated phenylpropanoids from *Illicium fargesii*, and neuroprotective activity of macranthol. *Chemical & Pharmaceutical Bulletin, 56*(8), 1201–1204.

Nakamura, T., Okuyama, E., & Yamazaki, M. (1996). Neurotropic components from star anise (*Illicium verum* Hook. fi l.). *Chemical & Pharmaceutical Bulletin, 44*(10), 1908.

Nie, W., Ding, L. F., Lei, T., Pan, Z. H., & Zhao, Q. S. (2021). Illilanceolide a, a unique *seco*-prezizaane sesquiterpenoid with 5/5/6 tricyclic scaffold from the fruits of *Illicium lanceolatum* A. C. *Smith. Tetrahedron Letters, 70*, 153022.

Nie, W., Ding, L. F., Tie-Lei Zhou, H. F., Bao, Y., Song, L. D., ... Zhao, Q. S. (2022). Seco-prezizanne sesquiterpenes and prenylated C6–C3 compounds from the fruits of *Illicium lanceolatum* A. *C. Smith. Chemistry & Biodiversity, 19*(1), e202100868.

Okuyama, E., Nakamura, T., & Yamazaki, M. (1993). Convulsants from star anise (*Illicium verum* Hook.F.). *Chemical & Pharmaceutical Bulletin, 41*(9), 1670–1671.

Schmidt, T. J. (1999). Novel seco-prezizaane sesquiterpenes from north american *illicium* species. *Journal of Natural Products, 62*(5), 684–687.

Schmidt, T. J., Gurrath, M., & Ozoe, Y. (2004). Structure-activity relationships of *seco*-prezizaane and picrotoxane/picrodendrane terpenoids by *Quasar* receptor-surface modeling. *Bioorganic & Medicinal Chemistry, 12*(15), 4159–4167.

Schmidt, T. J., Müller, E., & Fronczek, F. R. (2001). New allo-cedrane type sesquiterpene hemiketals and further sesquiterpene lactones from fruits of *Illicium floridanum*. *Journal of Natural Products, 64*(4), 411–414.

Schmidt, T. J., Okuyama, E., & Fronczek, F. R. (1999). The molecular structure of 2α-hydroxyneoanisatin and structure-activity relationships among convulsant sesquiterpenes of the *seco*-prezizaane and picrotoxane types. *Bioorganic & Medicinal Chemistry, 7*(12), 2857–2865.

Schmidt, T. J., Schmidt, H. M., Müller, E., Peters, W., & Fischer, N. H. (1998). New sesquiterpene lactones from *Illicium floridanum*. *Journal of Natural Products, 61*(2), 230–236.

Sy, L. K., & Brown, G. D. (1998). A prezizaane sesquiterpene from *Illicium angustisepalum*. *Phytochemistry, 49*(6), 1715–1717.

Tang, W. Z., Ma, S. G., Yu, S. S., Qu, J., Liu, Y. B., & Liu, J. (2009). Rearranged prenylated C6–C3 compounds and a highly oxygenated *seco*-prezizaane-type sesquiterpene from the stem bark of Illicium oligandrum. *Journal of Natural Products, 72*(6), 1017–1021.

Wang, G. W., Hu, W. T., Huang, B. K., & Qin, L. P. (2011). *Illicium verum*: A review on its botany, traditional use, chemistry and pharmacology. *Journal of Ethnopharmacology, 136*(1), 10–20.

Xia, Z. H., Yuan, C. R., & Zhang, Y. Y. (2021). Effect of nerve growth factor combined with medoba on senile Parkinson'sdisease and its effect on brain neurotransmitters, neurotrophic factors and inflammatory factors. *Journal of Clinical and Experimental Medicine, 20*(23), 2504–2508.

Yadav, R. N., Mondal, S., & Ghosh, S. (2011). An efficient stereoselective route to the construction of tricyclic core structure towards the synthesis of the sesquiterpenes of the *seco*-prezizaane family. *Tetrahedron Letters, 52*(16), 1942–1945.

Yang, C. S., Hashimoto, M., Baba, N., Takahashi, M., Kaneto, H., Kawano, N., & Kouno, I. (1990). A new toxic neoanisatin derivative from the pericarps of *Illicium majus*. *Chemical & Pharmaceutical Bulletin, 38*(1), 291–292.

Yin, P. J., Wang, J. S., Wang, P. R., & Kong, L. Y. (2012). Sesquiterpenes and lignans from the fruits of *Illicium simonsii* and their cytotoxicities. *Chinese Journal of Natural Medicines, 10*(5), 383–387.

Yokoyama, R., Huang, J. M., Hosoda, A., Kino, K., Yang, C. S., & Fukuyama, Y. (2003). *Seco*-prezizaane-type sesquiterpenes and an abietane-type diterpene from *Illicium minwanense*. *Journal of Natural Products, 66*(6), 799.

Zhang, G., Zhuang, P., Wang, X., Yu, S., Ma, S., Qu, J., ... Yu, D. (2013). Sesquiterpenes from the roots of *illicium jiadifengpi*. *Planta Medica Natural Products & Medicinal Plant Research, 79*(12), 1056–1062.

Zhang, J. P., Li, W. R., Yong, J. Y., Yang, J., & Ma, S. G. (2021). A new *seco*-prezizaane-type sesquiterpene lactone from stems and branches of *Illicium ternstroemioides*. *China Journal of Chinese Materia Medica, 46*(22), 5848–5852.

Zhu, Q., Tang, C. P., Ke, C. Q., Wang, W., Zhang, H. Y., & Ye, Y. (2009). Sesquiterpenoids and phenylpropanoids from pericarps of *Illicium oligandrum*. *Journal of Natural Products, 72*(2), 238–242.