Review

Chemical composition and pharmacological effects of the *Forsythia suspensa*

Jiayuan Wang, Zixuan Che, Yuzheng Xiang, Meng Zhang, Ying Li*, Yu Chen*

School of Life Science and Biopharmaceutics, Shenyang Pharmaceutical University, Shenyang 110016, China

Abstract

The dried fruit of *Forsythia suspensa* (*Oleaceae*), also known as *Forsythia*, is a traditional Chinese medicinal herb known for its heat-clearing and detoxifying properties. It is used to disperse nodules, reduce swelling, remove toxins, clear heat, and alleviate wind-heat syndromes. It also has hepatoprotective, anti-inflammatory, antiviral, antibacterial, anticancer, antioxidant, anti-aging, and anti-obesity effects, as well as potential therapeutic effects on Alzheimer's disease and diabetic nephropathy. It is used to treat scrofula, mastitis, wind-heat common cold, and other ailments. The review summarizes the chemical constituents and pharmacological effects of *F. suspensa*, aiming to provide a scientific foundation for its future development, research, and clinical utilization.

Keywords: *Forsythia suspensa*; pharmacological effects; chemical constituents

1 Introduction

Forsythia suspensa was originally documented in the Divine Farmer's Classic of Materia Medica. Research indicates that its roots, stems, leaves, flowers, fruits, and seeds were all used medicinally in ancient times. However, modern medicine exclusively employs its fruit for therapeutic purposes [1]. In the fall when the fruits are first ripe and yet green, they are harvested. The fruits are then steamed and sun-dried. After removing impurities, they are referred to as green *F. suspensa* (qingqiao). Mature *F. suspensa* (laoqiao) refers to fruits that are harvested when fully ripe and sun-dried, with impurities removed. According to the *Chinese Pharmacopoeia* (2025), mature and green *F. suspensa* are both classified under *F. suspensa*.

As the varieties of *F. suspensa* have evolved, so have the regions where this medicinal herb is cultivated. After the Song Dynasty, *F. suspensa* was primarily cultivated in Shanxi, Shandong, and Henan. Now, Shanxi, Henan, Shanxi, and Shandong are the main producing regions, with Shanxi and Henan being the largest contributors [2].

According to the Chinese Pharmacopoeia, *F. suspensa* has the ability to clear heat, reduce

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* Author to whom correspondence should be addressed. Address: School of Life Science and Biopharmaceutics, Shenyang Pharmaceutical University, Shenyang 110016, China; Tel.: +86-18341400530 (Yu Chen), +86-18341400610 (Ying Li); E-mail: gzweishengwu@126.com (Yu Chen), yyswalk@163.com (Ying Li).

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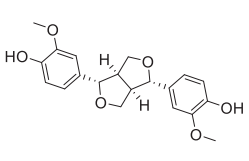
swelling and disperse nodules, and dispell wind-heat. It is indicated for conditions such as heat entering the ying level, high fever with thirst, mental confusion with rash, scrofula, mastitis, erysipelas, wind-heat common cold, boils and abscesses, and severe dysuria with heat [3]. Pharmacological studies have shown that *F. suspensa* exhibits a variety of pharmacological activities, but some of the mechanisms have not been elucidated. With advances in modern chemical analysis technology and pharmacological activity evaluation methods, further research on *F. suspensa* will be better supported and guided.

2 Chemical composition

A variety of bioactive compounds, including lignans, terpenoids, volatile oils, phenethyl alcohol glycosides, phenolic acids, and flavonoids, have been extracted from the fruit, roots, stems, leaves, and flowers of *F. suspensa*. Among these, lignans and phenethyl alcohol glycosides are the most abundant chemical constituents found in the plant.

2.1 Lignans

Lignans, a class of natural compounds primarily formed as dimers, are produced through the oxidative polymization of coumarin. There are 29 known lignans, including (+)-pinoresinol (**1**), (+)-phillyrin (**2**), forsythialanside E (**3**), (+)-pinoresinol monomethyl ether-4-O-*β*-D-glucoside (**4**), (+)-epipinoresinol-4-O-*β*-Dglucoside (**5**), hydroxypinoresinol4'-O-*β*-D-glucopyranoside (**6**), pinoresinol-4-O-*β*-D-glucopyranoside (**7**), hydroxypinoresinol (**8**), (+)-pinoresinol monomethyl ether (**9**), lariciresinol-4-O-*β*-D-glucoside (**10**), (-)-olivil-4'-O-*β*-D-glucoside (**11**), (+)-lariciresinol (**12**), (-)-olivil (**13**), forsythiayanoside A (**14**), forsythialan A (**15**), forsythialan B (**16**), forsythialan C (**17**), (-)-matairesinol (**18**), (-)-dimethylmatairesinol (**19**), (-)-arctigenin (**20**), (-)-arctiin (**21**), (-)-matairesinoside (**22**), 4-O-demethylforsythenin (**23**), bisepoxyforsythide (**24**), isolariciresinol (**25**), isoolivil (**26**), (+)-phillygenin (**27**), forsythiayanoside B (**28**), and (-)-secoisolariciresinol (**29**) [4]. The structures of these lignans are shown in Fig. 1.



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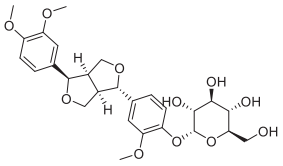

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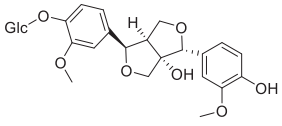

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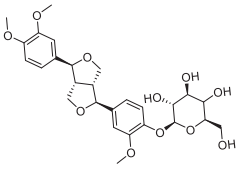

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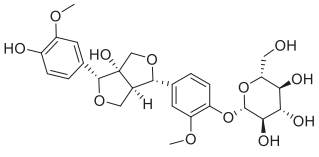

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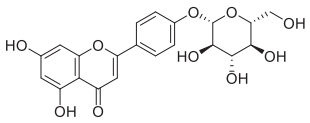

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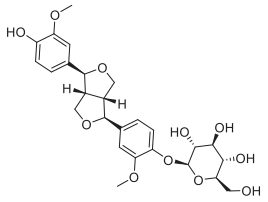

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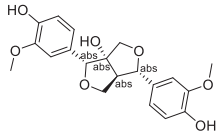

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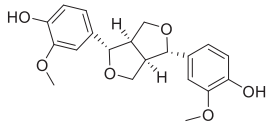

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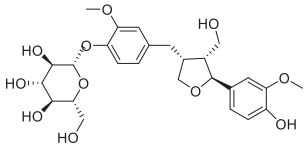

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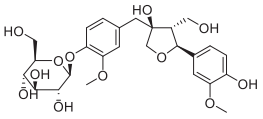

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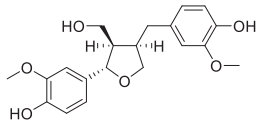

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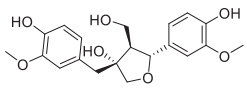

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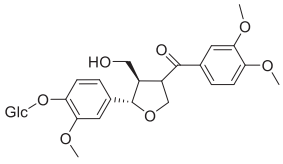

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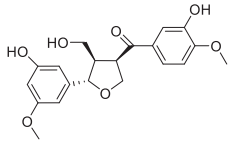

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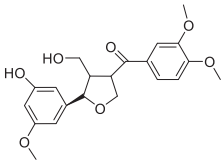

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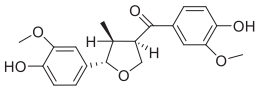

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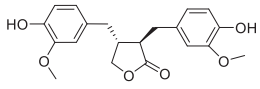

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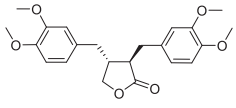

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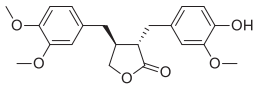

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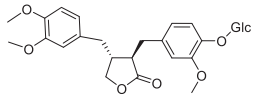

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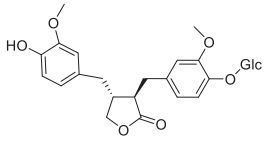

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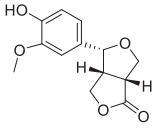

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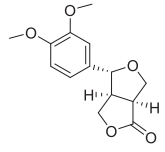

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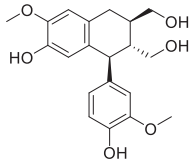

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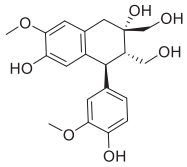

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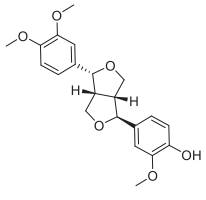

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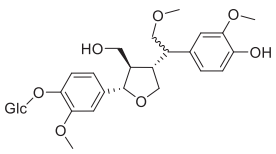

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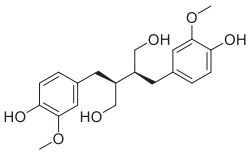
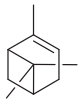


29

Fig. 1 Structures of lignans in *F. suspensa*

2.2 Terpenoids and volatile oils

The volatile oil of *F. suspensa* is mainly composed of terpenoid compounds, including monoterpenes, sesquiterpenes, diterpenes, and triterpenes. Research indicates that *F. suspensa* contains a total of 56 terpenoid and volatile oil components, including *α*-pinene (**30**), *β*-pinene (**31**), *α*-phellandrene (**32**), *β*-phellandrene (**33**), *α*-terpinene (**34**), *γ*-terpinene (**35**), camphene (**36**), sabinene (**37**), limonene (**38**), *α*-thujene (**39**), *β*-myrcene (**40**), *β*-ocimenol (**41**), 3-carene (**42**), p-cymene (**43**), geranic acid (**44**), thujone (**45**), *α*-terpineol (**46**), terpinine-4-ol (**47**), linalool (**48**), (–)-myrtenal (**49**), p-cymen-8-ol (**50**), trans-geraniol (**51**), camphor (**52**), perilla aldehyde (**53**), geraniol (**54**), jacaranone ethyl ester (**55**), dehydro-vomifoliol (**56**), *β*-terpinene (**57**), *α*-copaene (**58**), cubebene (**59**), *α*-cadinol (**60**), germacrene (**61**), isoaromadendrene epoxide (**62**), adoxosidic acid (**63**), 4,8,13-duvatriene-1,3-diol (**64**), androstanolone (**65**), terpinolene (**66**), 18-hydroxy-7-oxolabda-8(9),13(*E*)-dien-15-oic acid (**67**), p-cymene (**68**), o-cymene (**69**), 2-carene (**70**), 4-carene (**71**), D-sylvestrene (**72**), eucalyptol (**73**), forsythidin A (**74**), haplopappic acid (**75**), dehydropinifolic acid (**76**), eucarvone (**77**), labda-8(17),13(*Z*)-dien-15,18-dioic acid (**78**), ursolic acid (**79**), (+)-camphor (**80**), oleanolic acid (**81**), betulinic acid (**82**), vanillin (**83**), hovenic acid (**84**), and T-muurolol (**85**) [4-5]. Structures of the triterpenoid components of *F. suspensa* are shown in Fig. 2.



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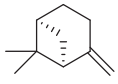

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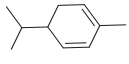

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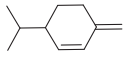

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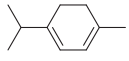

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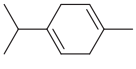

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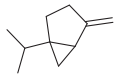

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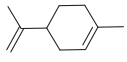

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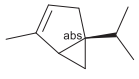

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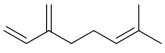

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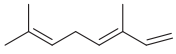

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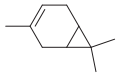

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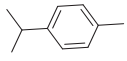

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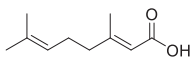

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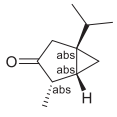

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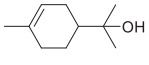

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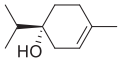

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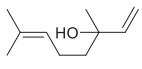

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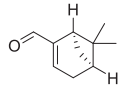

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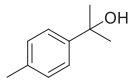

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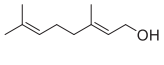

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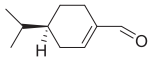

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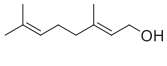

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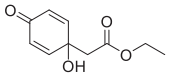

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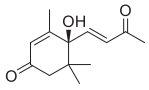

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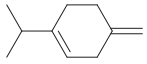

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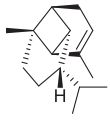

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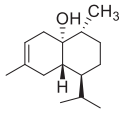

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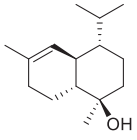

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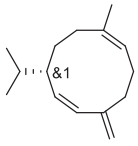

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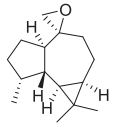

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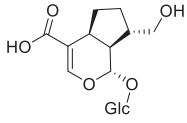

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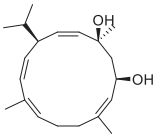

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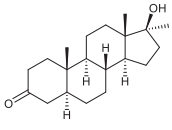

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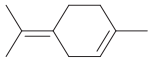

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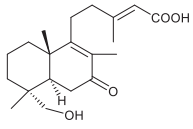

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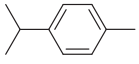

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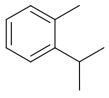

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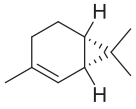

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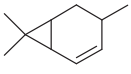

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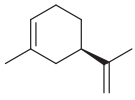

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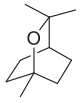

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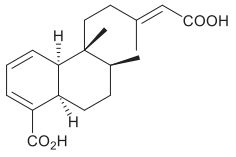

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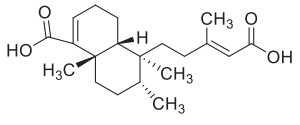

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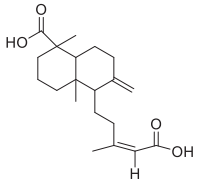

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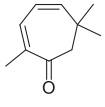

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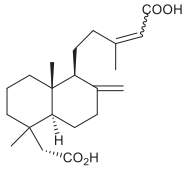

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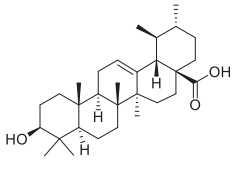

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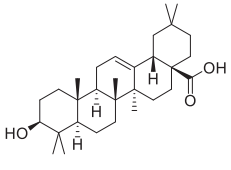

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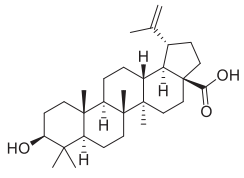

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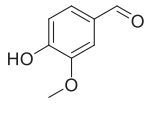

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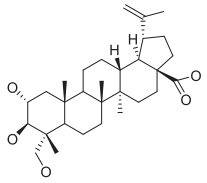

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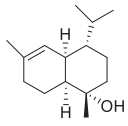

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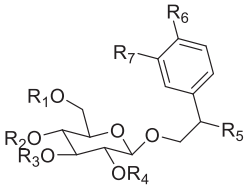
Fig. 2 Structures of terpenoids and volatile oils in *F. suspensa*

2.3 Phenethyl alcohol glycosides

Phenethyl alcohol glycosides are found at relatively high levels in the leaves of *F. suspensa*. To date, 30 phenethyl alcohol glycosides and related substances have been discovered in *F. suspensa*, including forsythiaside A (**86**), forsythoside B (**87**), forsythoside C (**88**), forsythoside D (**89**), forsythoside E (**90**), forsythoside F (**91**), forsythoside G (**92**), forsythoside H (**93**), forsythoside I (**94**), forsythoside J (**95**), forsythoside K (**96**), isoforsythiaside (**97**), acteoside (**98**), calceolarioside A (**99**), calceolarioside B (**100**), calceolarioside C (**101**), lianqiaoxinside A (**102**), lianqiaoxinside C (**103**), plantainoside A (**104**), plantainoside B (**105**), suspensaside B (**106**), Forsythenside K (**107**), *β*-hydroxyacteoside (**108**), 2-(3,4-Dihydroxyphenyl) ethyl *β*-D-glucopyranoside (**109**), salidroside (**110**), phenethyl *β*-D-xylopyranosyl-(1→6)-*β*-D-glucopyranoside (**111**), 7*R*-suspensaside methyl ether (**112**), 7*S*-suspensaside methyl ether (**113**), lianqiaoxinosideB (**114**), and suspensaside A (**115**). The *Chinese Pharmacopoeia* (2025) lists forsythoside A as the quality indicator for *F. suspensa* herbal substance [4-5]. The structures and details of the phenethyl alcohol glycosides found in *F. suspensa* are shown in Fig. 3 and Table 1.



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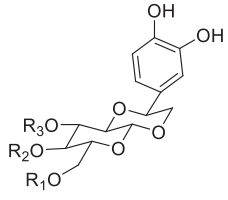

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Fig. 3 Structures of phenethyl glycosides in *F. suspensa*

Table 1 Phenethyl alcohol glycosides in *F. suspensa*

No.	Name	R_1	R_2	R_3	R_4	R_5	R_6	R_7
86	forsythiaside A	Rha	Caffeoyl	H	H	H	OH	OH
87	forsythoside B	Api	Caffeoyl	Rha	H	H	OH	OH
88	forsythoside C	Rha	Caffeoyl	H	H	OH	OH	OH
89	forsythoside D	Rha	H	H	H	OH	OH	OH

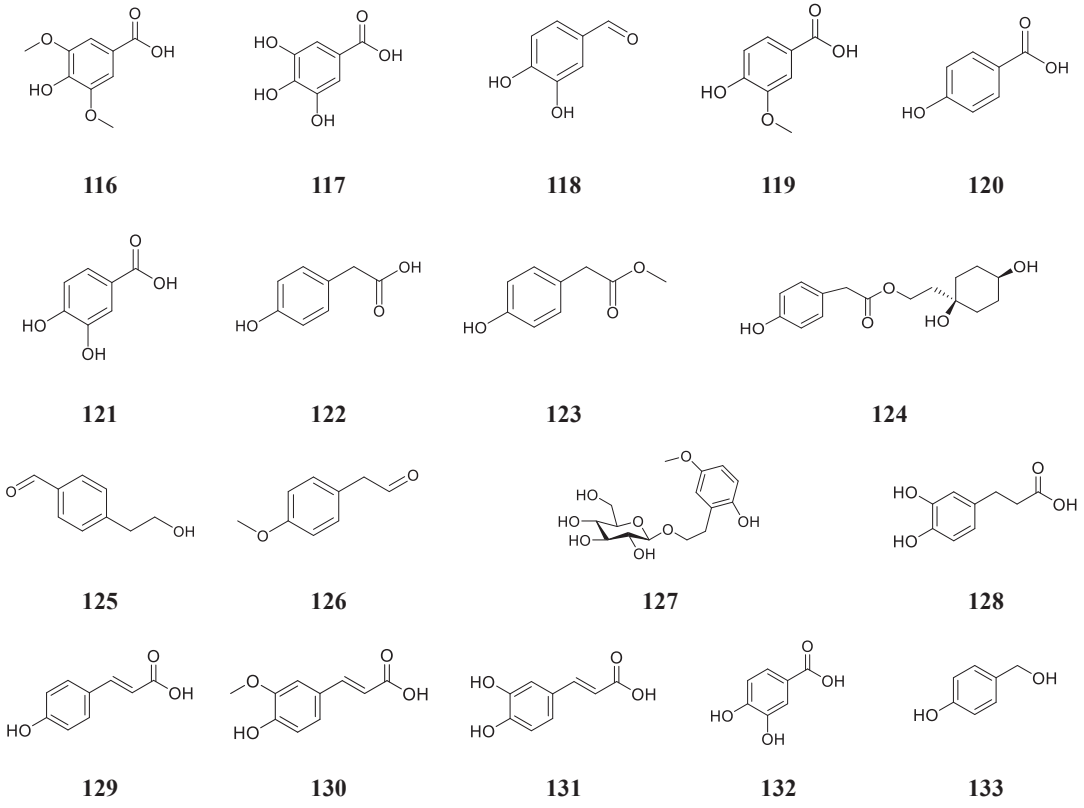
(to be continued)

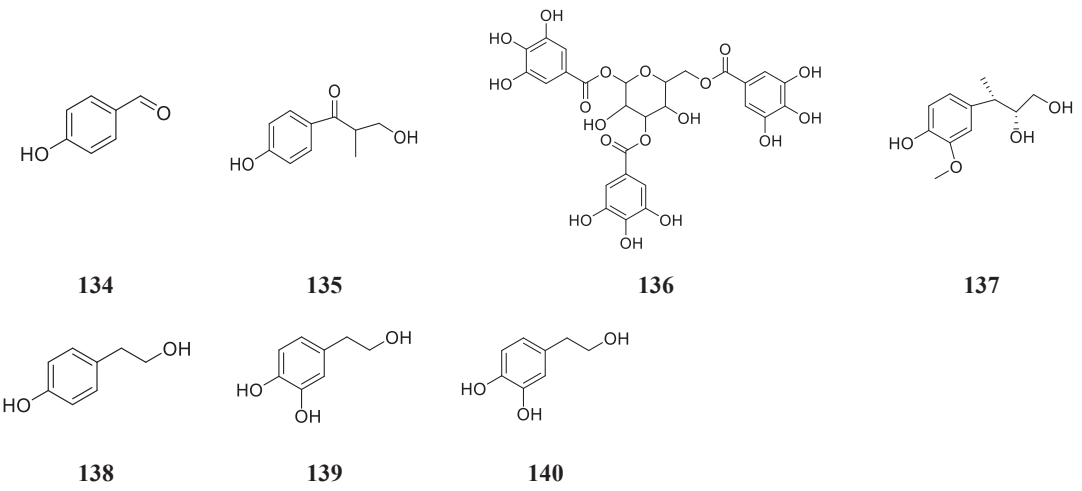
Continued Table 1

No.	Name	R_1	R_2	R_3	R_4	R_5	R_6	R_7
90	forsythoside E	Rha	H	H	H	H	OH	OH
91	forsythoside F	Xyl	Caffeoyl	Rha	H	H	OH	OH
92	forsythoside G	(2-O-methyl)	Caffeoyl	Rha	H	H	OH	OH
93	forsythoside H	Rha	H	H	Caffeoyl	H	OH	OH
94	forsythoside I	Rha	H	Caffeoyl	H	H	OH	OH
95	forsythoside J	Xyl	Caffeoyl	H	H	OCH_3	OH	OH
96	forsythoside K	Rha	Caffeoyl	H	H	OCH_3	OH	OH
97	isoforsythiaside	Rha	H	Caffeoyl	HH\	H	OH	OH
98	acteoside	H	Caffeoyl	Rha	H	H	OH	OH
99	calceolarioside A	Caffeoyl	H	H	H	H	OH	OH
100	calceolarioside B	H	Caffeoyl	H	H	H	OH	OH
101	calceolarioside C	Xyl	Caffeoyl	H	H	H	OH	OH
102	lianqiaoxinside A	Rha	H	Caffeoyl	H	H	OH	OH
103	lianqiaoxinside C	Xyl	H	Caffeoyl	H	H	OH	OH
104	plantainoside A	H	H	Caffeoyl	H	H	OH	OH
105	plantainoside B	H	H	H	Caffeoyl	H	OH	OH
106	suspensaside B	Rha	Caffeoyl	H	H	$O(CH_2)_3CH_3$	OH	OH
107	forsythenside K	Rha	P-hydroxycinamoyl	H	H	H	OH	OH
108	β-hydroxyacteoside	H	Caffeoyl	Rha	H	OH	OH	OH
109	2-(3,4-Dihydroxyphenyl)ethyl *β*-D-glucopyranoside	H	H	H	H	H	H	H
110	salidroside	H	H	H	H	H	OH	H
111	phenethyl *β*-D-xylopyranosyl-(1→6)-*β*-D-glucopyranoside	Xyl	H	H	H	H	H	H
112	7*R*-suspensaside methyl ether	Rha	Caffeoyl	H	H	OCH_3	OH	OH(7*R*)
113	7*S*-suspensaside methyl ether	Rha	Caffeoyl	H	H	OCH_3	OH	OH(7*S*)
114	lianqiaoxinosideB	Rha	H	Caffeoyl				
115	suspensaside A	Rha	Caffeoyl	H				

2.4 Phenolic acids

Phenolic acids are classified into three types: the C6-C1 type with benzoic acid as the parent nucleus, such as cinnamic acid and gallic acid; the C6-C2 type with phenylacetic acid as the parent nucleus, such as p-hydroxyphenylacetic acid and methyl p-hydroxyphenylacetate; the C6-C3 type with cinnamic acid as the parent nucleus, such as caffeic acid and trans-coumaric acid. In most phenolic acids, the phenolic hydroxyl group is prone to oxidation into a carbonyl group, leading to loss of bioactivity [4, 6]. Research has identified a total of 25 phenolic acid compounds in *F. suspensa*, including syringic acid (**116**), gallic (**117**), protocatechuic aldehyde (**118**), vanillic acid (**119**), p-hydroxybenzoic acid (**120**), Protocatechuic acid (**121**), methylp-hydroxyphenylacetate (**122**), p-hydroxyphenylacetic acidmethylester (**123**), rengy olester (**124**), 4(-2-hydroxyethyl) benzaldehyde (**125**), methoxyphenylacetaldehyde (**126**), forsythiayarosiade C (**127**), caffeic acid (**128**), trans-coumaric acid **(129**), transferulic acid (**130**), (*E*)-caffeic acid methylester (**131**), protocatechuic acid (**132**), p-hydroxybenzyl alcohol (**133**), p-hydroxybenzaldehyde (**134**), 1(-4-hydroxyphenyl)-2,3-dihydroxyacetone (**135**), tannic acid (**136**), forsythiayarosiade D (**137**), p-hydroxyphenylethanol (**138**), 3,4-dihydroxyphenylethanol (**139**), and 4-hydroxyphenethy12(-4-hydroxyphenl)acetate (**140**). Structures of phenolic acids found in *F. suspensa* are shown in Fig. 4.





134 **135** **136** **137**

138 **139** **140**

Fig. 4 Structures of phenolic compounds in *F. suspensa*

2.5 Flavonoids

One important type of secondary metabolites found in *F. suspensa* is flavonoids. The two main flavonoids in the plant, quercetin and rutin, have strong antibacterial and anti-inflammatory properties. Research has identified a total of 10 flavonoid compounds in *F. suspensa*, including quercetin (**141**), isoquercetin (**142**), astragalin (**143**), rutin (**144**), galuteolin (**145**), kaempferol (**146**), isorhamnetin (**147**), hesperidin (**148**), lunteolin (**149**), and hyperoside (**150**). Structures and details of the flavonoids found in *F. suspensa* are shown in Fig. 5 and Table 2.

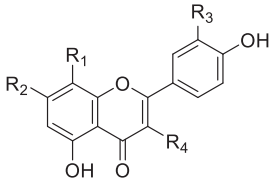


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Fig. 5 Structures of flavonoids in *F. suspensa*

Table 2 Flavonoids in *F. suspensa*

No.	Name	R_1	R_2	R_3	R_4
141	quercetin	H	OH	OH	OH
142	isoquercetin	H	OH	OH	OGlc
143	astragalin	H	OH	H	OGlc
144	rutin	H	OH	OH	OGlc-Rha
145	galuteolin	H	OGlc	OH	H
146	kaempferol	H	OH	H	OH

(to be continued)

Continued Table 2

No.	Name	R_1	R_2	R_3	R_4
147	isorhamnetin	H	OH	OCH_3	OH
148	hesperidin	H	Glc-Rha	OCH_3	H
149	lunteolin	H	OH	OH	H
150	hyperoside	H	OH	OH	OGlc

3 Pharmacological activity

3.1 Anti-inflammatory effects

Inflammation is the body's natural defense mechanism which is mediated by the release of soluble proteins or tiny immunomodulatory peptide molecules in response to inflammatory mediators acting on immune cells, thereby participating in or triggering inflammatory reactions. The anti-inflammatory mechanisms of *F. suspensa* have been extensively studied. Research indicates that its anti-inflammatory effects primarily involve regulating inflammatory mediators and modulating signaling pathways, including nuclear factor E2-related factor 2 (Nrf2), mitogen-activated protein kinase (MAPK), nuclear factor *κ*B (NF-*κ*B), phosphoinositide 3-kinase (PI3K)/protein kinase B (Akt), JAK/signal transducer and activator of transcription (STAT), protein kinase R-like ER kinase (PERK), and NLRP3 (NOD-like receptor protein 3) inflammasome signaling pathways [3, 7-8]. Studies suggest that the main anti-inflammatory constituents of *F. suspensa* are flavonoids, phenethyl alcohol glycosides, and lignans. For instance, *F. suspensa* flower essential oil, neolignans from *F. suspensa* flowers, lignan lactones B and C from *F. suspensa* leaves, and forsythoside A from *F. suspensa* all have strong anti-inflammatory properties.

Upon exposure to inflammatory stimuli, NF-*κ*B becomes activated and moves to the nucleus, where it initiates the expression of inflammation-related genes. The Nrf2/heme oxygenase-1 (HO-1) pathway counteracts this process by blocking NF-*κ*B activation. Using *in vitro* and *in vivo* models of inflammatory injury, Wang et al. found that forsythoside A inhibits the TLR4/MAPK/NF-*κ*B and MLCK/MLC2 signaling pathways by activating the PPAR-*γ*/RXR-*α* complex [9]. This inhibition lowers the release of inflammatory cytokines and prevents the disruption of the epithelial barrier. In a mouse model of lipopolysaccharide-induced acute lung injury, forsythoside A effectively alleviated lung and colon inflammation. The underlying mechanism can be summarized as follows: Lipopolysaccharide (LPS) binds to and activates TLR4 on the cell surface, thus activating the downstream MAPK signaling pathway. This active MAPK pathway subsequently phosphorylates and activates NF-*κ*B, which further controls the production and release of pro-inflammatory molecules like iNOS, TNF-*α*, IL-1*β*, and IL-6. These events collectively exacerbate inflammatory responses in lung and colon tissues. By activating the PPAR-*γ*/RXR-*α* complex, forsythoside A inhibits TLR4 activation, suppresses MAPK phosphorylation, and attenuates NF-*κ*B nuclear translocation, thereby blocking this route at its source. Consequently, the synthesis and release of proinflammatory factors are reduced, leading to the diminished inflammation in the intestines and lungs. Wang et al. administered 2.5, 5, and 10 *μ*g/mL forsythoside A to BV2 microglia and primary microglia and found that forsythoside A reduced the expression of TNF-*α*, IL-1*β*, NO, and PGE2 in cells, which in turn reduced the lipopolysaccharide (LPS)-induced inflammatory responses [10].

Su et al. established an *in vitro* rheumatoid arthritis model by treating MH7A synovial fibroblasts with IL-1β [11]. Both JAK and STAT protein levels were elevated in these cells. Forsythoside A inhibited cell migration and invasion particularly by reducing JAK and STAT phosphorylation, indicating that forsythoside A suppresses the JAK/STAT signaling pathway. Tang et al. established an LPS-induced RAW 264.7 macrophage model and found that forsythoside A exerts its protective effects against LPS-induced inflammation and oxidative stress in RAW 264.7 cells by inhibiting the PI3K/Akt signaling pathway and activating the Nrf2/HO-1 signaling pathway [12]. Lang et al. found that treatment with forsythoside A in methotrexate (MTX)-induced rats reduced peripheral blood leukocyte, neutrophil, and lymphocyte counts, suppressed NLRP3, cleaved cathepsin 1, and cleaved IL-1β levels, and decreased NLRP3 IOD [13]. Therefore, forsythoside A alleviates MTX-induced inflammatory responses by inhibiting NLRP3 inflammasome activation and reducing the release of proinflammatory factors TNF-α, IL-1β, and IL-18.

Additionally, studies have found that lignan lactones B and C isolated from *F. suspensa* leaves, *F. suspensa* flower essential oil, and novel lignans in *F. suspensa* flowers all exhibit certain anti-inflammatory effects. Deng et al. isolated lignan lactones B and C from *F. suspensa* leaves and observed their anti-inflammatory activity against LPS-induced macrophages [14]. Yang et al. demonstrated that *F. suspensa* flower essential oil alleviates ear edema in mice by reducing ear tissue water content, deceasing dermal and epidermal thickness, and inhibiting NO production, thereby exhibiting anti-inflammatory effects [15]. Kim et al. demonstrated that neolignans from *F. suspensa* flowers inhibit JAK1/2 and STAT1/3 phosphorylation in a mouse model of colitis [16]. By suppressing inflammatory cell infiltration, neolignans inhibit NF-κB and STAT1/3 signaling pathways, thereby alleviating colitis symptoms.

3.2 Antibacterial activity

F. suspensa possesses broad-spectrum antibacterial properties. Forsythoside, as the primary component of *F. suspensa*, exhibits potent antibacterial effects against both Gram-positive and Gram-negative bacteria. Research by Li et al. demonstrated that forsythoside attenuated titanium (Ti)-induced NF-κB signaling by targeting IκB kinase-α (IKKα) in macrophages [17]. This affects the expression of NF-κB downstream inflammatory cytokines, significantly inhibiting the activity of Staphylococcus aureus and methicillin-resistant Staphylococcus aureus (MRSA) induced by titanium implants. Research indicates that forsythoside exhibits pronounced antibacterial effects against pathogenic bacteria including Escherichia coli, Klebsiella pneumoniae, Pseudomonas aeruginosa, and Staphylococcus aureus [3].

Additionally, studies have demonstrated that *F. suspensa* essential oil, *F. suspensa* polysaccharides, *F. suspensa* seed volatile oil, and *F. suspensa* leaf extract all exhibit potent antibacterial effects. *F. suspensa* essential oil alters the permeability and integrity of cell membranes, leading to nucleic acid and protein leakage in Escherichia coli and Staphylococcus aureus, thereby exerting its antibacterial activity. *F. suspensa* polysaccharides exhibit potent antibacterial activity against Shiga toxin-producing Escherichia coli (STEC) harboring the SHV-12 extended-spectrum beta-lactamase (ESBL) gene, effectively supressing bacterial growth and enlarging the diameter of the inhibition zone. *F. suspensa* seed essential oil induces cell death by disrupting the cell wall and membrane structures of three indicator bacteria—Escherichia coli, Staphylococcus aureus, and Saccharomyces cerevisiae-leading to the leakage of cellular contents. It also interferes with proteins or protein synthesis

enzymes during bacterial growth, thereby disrupting the cell growth cycle. *F. suspensa* leaf extract (FSLE) exhibits the strongest inhibitory effect against Staphylococcus aureus, followed by Escherichia coli, while showing weaker activity against Bacillus subtilis. No inhibitory effect is observed against Rhizopus or Aspergillus niger [3, 18-19].

3.3 Antiviral effects

F. suspensa can interfere with multiple stages of the viral life cycle, thereby inhibiting viral replication and proliferation. Research has demonstrated that *F. suspensa* exhibits antiviral activity against influenza viruses, coronaviruses (CoVs), herpes viruses (HSV), respiratory syncytial viruses (RSV), avian infectious bronchitis virus (IBV), and porcine reproductive and respiratory syndrome virus. The antiviral components in *F. suspensa* are mainly attributed to phenethyl alcohol glycosides, flavonoids, and volatile oils. For instance, phenethyl alcohol glycosides include forsythoside A and forsythoside B; flavonoids include forsythoside and quercetin; and volatile oils include *α*-pinene, *β*-pinene, and forsythol.

Zheng et al. found that forsythoside A alleviates influenza virus-induced immunopathological damage and inflammatory responses by modulating the TLR7 signaling pathway [20]. Specifically, it downregulates the expression of TLR7, MyD88, and NF-*κ*B expression in the lungs while modulating the Th1/Th2 and Th17/Treg ratios of immune cells in the spleen, suggesting that forsythoside A exerts antiviral effects through immune regulation.

Ma et al. demonstrated that forsythoside significantly inhibits the replication of SARS-CoV-2 and HCoV-229E, reduces the expression of TNF-*α*, IL-6, IL-1*β*, monocyte chemotactic protein-1, and interferon-γ-induced protein 10 mRNA, decreases p-NF-*κ*Bp65 and p-IκB*α* protein expression, and simultaneously increases I*κ*B*α* expression in human hepatocellular carcinoma Huh-7 cells to suppress viral replication [21]. Furthermore, research has demonstrated that *F. suspensa* extract prolongs survival of mice with herpes simplex encephalitis (HSE) by downregulating gene expression of TNF-*α*, IL-1*β*, and IFN-*α*, thereby exerting therapeutic effects [22].

Fuli et al. reported that the combination of forsythoside and forsythoside lipid showed significant efficacy in treating viral influenza and pneumonia, and also demonstrated notable therapeutic effects against multiple viruses including respiratory syncytial virus, enterovirus, herpes simplex virus, and coxsackievirus [23].

Forsythoside A inhibits the infectious bronchitis virus (IBV) mainly by regulating the PI3K/Akt/NF-*κ*B signaling pathway, thereby reducing IBV-induced autophagy and apoptosis. This action greatly suppresses IBV replication and mitigates virus-induced cellular damage. Studies indicate that forsythoside A upregulates the expression of intracellular receptors, including MDA5, LGP2, and NLRC5 in IBV-infected cells. It also enhances the expression of antiviral genes such as IRF7, IFN-*α*, and IFN-*β*, suggesting that FTA-activated intracellular receptors and antiviral genes are associated with its anti-IBV effects [8, 22].

Liang et al. demonstrated that forsythoside A enhances the phagocytic capacity of porcine alveolar macrophage 3D4/2 cells, increases IL-6 and TNF-*α* secretion by 3D4/2 cells, suppresses IL-10 secretion, inhibits PRRSV infection of 3D4/2 cells, reduces apoptosis, interferes with viral replication processes, and prevents viral release, thereby exerting an anti-PRRSV effect [22].

3.4 Antioxidant effects

Numerous constituents of *F. suspensa* exhibit antioxidant activity. Forsythoside A, B, H, and I isolated from *F. suspensa* leaves

significantly increase the activity of superoxide dismutase (SOD) and catalase (CAT) in H_2O_2-induced RAW264.7 macrophages, increase the cellular content of glutathione peroxidase (GSH-Px), alleviate oxidative stress induced by H_2O_2. catalase (CAT) activity in H_2O_2-induced RAW264.7 macrophages, increase intracellular glutathione peroxidase (GSH-Px) content, alleviate H_2O_2-induced oxidative damage, and reduce malondialdehyde (MDA) levels in a dose-dependent manner. In addition, these compounds exhibit potent scavenging activity against 1,1-diphenyl-2-picrylhydrazyl radical (PPH), 2,2-diphenyl-1-(2,4,6-trinitrophenyl)hydrazyl (ABTS), DPPH], 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid (ABTS) radicals, and superoxide anion radicals, demonstrating superior scavenging capacity compared to components such as forsythoside and forsythoside A.

Li et al. administered forsythoside at doses of 5, 15, and 45 mg/kg to mice via gavage for eight consecutive weeks. They discovered that forsythoside reduced lipid peroxidation levels and alleviated D-galactose-induced memory impairment in mice by enhancing the activities of SOD and GSH-Px, which in turn mitigated brain aging and serum oxidative stress. Forsythoside mitigated hippocampus injury by concurrently upregulating the expression of Nrf2, HO-1, and NQO1 proteins and downregulating Keap1 expression [23]. In an experimental study on aged rats, Yang et al. demonstrated that forsythoside successfully inhibited oxidative stress responses by decreasing the expression levels of associated proteins caspase-3 and caspase-9, increasing SOD activity, lowering MDA content, and elevating GSH levels [3]. Research by Yu et al. indicated that forsythoside exhibited strong scavenging activity against DPPH and ABTS radicals, but relatively moderate inhibitory effects on lipid peroxidation. The water extract of *F. suspensa* leaves ameliorated *β*-amyloid (A*β*) 25-35-induced damage in PC12 cells while exhibiting potent acetylcholinesterase inhibition and dose-dependent antioxidant activity. Phenethyl alcohol glycosides and flavonoids in *F. suspensa* demonstrated notable antioxidant potency [3].

3.5 Antitumor effects

Lignans, flavonoids, and triterpenoids in *F. suspensa* are the primary components responsible for its antitumor effects. Network pharmacology studies indicate associations with targets such as AKT1, IL6, ESR1, EGFR, EGF, and CCND1 [7]. For instance, forsythoside induces cancer cell apoptosis and inhibits proliferation by blocking the STAT3 signaling pathway, downregulating JAK2 expression levels, and upregulating SHP-1 expression through the JAK2/STAT3 signaling pathway [23].

Research has also shown that the triterpene F90 from *F. suspensa* leaves can inhibit the proliferation of breast cancer MCF-7 and MDA-MB-231 cells and induce apoptosis. *F. suspensa* extract LQ-4 inhibits proliferation and induces apoptosis in cervical cancer HeLa cells and gastric cancer SGC-7901 cells. Dammarane-type triterpenoids extracted from *F. suspensa* exhibit anticancer effects on gastric cancer SGC-7901, BGC-823, and MKN45 gastric cancer cells, HepG2 liver cancer cells, and PC-3 prostate cancer cells in a dose-dependent manner. As a broad-spectrum antitumor Chinese herbal medicine, *F. suspensa* presents significant potential for further research and development [3].

3.6 Hepatoprotective effects

Forskolin reduces the activity of alanine aminotransferase (ALT) and aspartate aminotransferase (AST), downregulates fatty acid synthase (FAS) protein expression and the phosphorylation of acetyl-CoA carboxylase, thereby repairing damage to high-fat liver cells and

exerting hepatoprotective effects [3]. In addition, forsythoside also alleviates aflatoxin-induced liver damage by inhibiting the NF-κB signaling pathway while activating the Nrf2 signaling pathway, an antioxidant stress-related transcription factor. Song et al. reported significant hepatoprotective effects of forsythoside against CCl_4-induced liver injury in mice, which is attributed to its antioxidant activity and inhibition of cytochrome P450 2E1 (CYP2E1) [23].

Forsythoside exerts hepatoprotective effects by reducing serum levels of ALT, AST, and total bilirubin. This action is associated with its ability to enhance antioxidant enzyme activity in liver tissue and reduce the expression of inflammatory mediators such as TNF-α and IL-8. Moreover, the water extract of *F. suspensa* demonstrates protective effects against CCl_4-induced liver injury. Its mechanism involves inhibiting hepatic stellate cell (HSC) activation, reducing extracellular matrix (ECM) deposition in hepatocytes, and reversing epithelial-mesenchymal transition (EMT) [7].

3.7 Neuroprotective effects

Inflammation and oxidative stress are central factors in the progression of neurodegenerative diseases. *F. suspensa*, with its anti-inflammatory and antioxidant properties, demonstrates neuroprotective effects by effectively alleviating neuroinflammation and inhibiting neuronal death. It has shown protective efficacy in conditions such as Alzheimer's disease and Parkinson's disease [8].

The development of Alzheimer's disease (AD) is closely associated with the deposition of β-amyloid (Aβ), while elevated levels of 2-arachidonoylglycerol (2-AG) can inhibit Aβ accumulation. Furthermore, inflammatory markers are overexpressed in the brains of AD patients, indicating that inflammation is intrinsically linked to the onset and development of AD.

Chen et al. demonstrated that forsythoside can reverse the decrease in 2-AG levels induced by β-amyloid fragment 25-35 (Aβ25-35) damage. Forsythoside inhibits cyclooxygenase-2 (COX-2) activity by forming six hydrogen bonds at the COX-2 active site (IC_{50} = 4.89 μmol/L), inhibits the expression of monoglyceride lipase (MAGL) protein, and modulates cannabinoid receptor 1 (CB1R)-dependent NF-κB protein levels to elevate 2-AG content, thereby achieving therapeutic effects against Alzheimer's disease [7].

The water extract of *F. suspensa* leaves inhibits cholinesterase activity, exhibits antioxidant effects, and demonstrates a dose-dependent response. Forsythoside A significantly activates dopaminergic signaling pathways, suppresses iron deposition and lipid peroxidation, blocks IKK/IκB/NF-κB signaling activation, and promotes the production of anti-inflammatory factors in the brain [3, 24].

4 Conclusion

This review provides a detailed overview of the chemical constituents and pharmacological effects of the traditional Chinese medicinal herb *F. suspensa*. It is characterized by the presence of lignans, terpenoids, volatile oils, phenethyl alcohol glycosides, phenolic acids, flavonoids, and other components, with lignans and phenethyl alcohol glycosides being its primary constituents. *F. suspensa* has demonstrated a wide range of anti-inflammatory, antibacterial, antiviral, antioxidant, antitumor, hepatoprotective, and neuroprotective effects, underscoring its significant clinical potential. However, certain mechanisms of action remain to be fully explored. With the continued advancements in modern medical science and technology, future research on *F. suspensa* is expected to deepen our undertanding and further expand its scope of application.

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