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Review

Apiaceae medicinal plants: A review of traditional uses, phytochemistry, bolting and flowering, and controlling approaches

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Abstract: *Ethnopharmacological relevance*: Apiaceae plants have been widely used as traditional Chinese medicines (TCMs) for the treatment of removing dampness to relieve pain, relaxing tendons, and activating blood, as well as relieving superficies and dispelling cold.

Aim of the review: This review aims to summarize the traditional use, phytochemistry, and modern pharmacological use of Apiaceae medicinal plants (AMPs), highlight the effect of bolting and flowering (BF) on yield and quality, and provide a basis for controlling the BF.

Materials and methods: All literatures involved in AMPs were searched using various online databases (*e.g.,* PubMed, Web of science, Google Scholar, Springer, and CNKI). Additional information was collected from ethnobotanical literature focusing on herbs from Flora of China and local herbal classic literature.

Result: A total of 228 AMPs have been recorded to be used as TCMs, with 6 medicinal parts (*i.e.*, the whole plants, rhizomes and/or roots, stems, leaves, fruits, and seeds) categorized, 72 traditional uses (*e.g.*, relieving pain, dispelling wind, and eliminating dampness) enriched, 62 modern pharmacological uses (*e.g.*, anti-inflammatory, antioxidative, and antitumor activities) enriched, and 5 main kinds of metabolites (*i.e.*, polysaccharides, alkaloids, phenylpropanoids, flavonoids, and terpenoids) categorized. Based on the influence level of BF on the yield and quality, 38 rhizomatous AMPs are categorized into 3 classes including: significantly affected, differently affected to some extent, and no significantly affected. Although the mechanism of

BF inducing the rhizome lignification has been revealed to some extent, and several attempts have been made to control the BF, especially in *Angelica sinensis*, the problem of BF has not been solved in the practical production.

Conclusions: So far, the traditional use of the 228 AMPs has been recorded, while the phytochemistry and modern pharmacological researches are still limited, thus, it is a treasure to find out new therapeutic agents. Since the BF regulated by internal factors and external factors have been demonstrated, and several key genes involved in BF have been identified, thus, it is available to control the BF by planting with standard techniques and innovating new cultivars using the CRISPR/Cas9 gene editing system. This review will provide useful references for the exploration and utilization, as well as the improvement of yield and quality of AMPs.

Key words: Apiaceae plant; Traditional use; Phytochemistry; Bolting and flowering; Controlling approach; Lignification

1. Introduction

Apiaceae (alt. Umbelliferae) is one of the largest angiosperm families including 300 genera (3000 species) in the world and 100 genera (614 species) in China (Wei et al., 2019). Apiaceae plants have been widely used as medical healthcare, nutrition, food industry, and other fields (Yuan, 1999). Currently, 55 genera (230 species) of Apiaceae plants have been applied in medical healthcare, and over 20 species have been widely used as traditional Chinese medicines (TCMs) (Zhao and Yan, 2020). Extensive studies have demonstrated that Apiaceae medicinal plants (AMPs) present a variety of pharmacological properties for the treatment of central nervous system, cardiovascular, and respiratory system diseases, amongst others (Cai, 2011; Wei et al., 2019). These pharmacological activities are largely associated with bioactive metabolites such as polysaccharides, alkaloids, phenylpropanoids (simple phenylpropanoids and coumarins), flavonoids, and polyene alkynes (Li et al., 2022a; Liu et al., 2002; Wei et al., 2019).

In China, Apiaceae plants have been primarily used as traditional medicines for main treatment of removing dampness to relieve pain, relaxing tendons, and activating blood, as well as relieving superficies and dispelling cold (Wei et al., 2019; Yuan, 1999). For example, rhizomatous and whole AMPs are mainly used for the treatment of common cold due to wind-cold, cough, asthma, rheumatic arthralgia, as well as ulcerative carbuncle and pyogenes infections; plants used fruits AMPs are mainly used for the treatment of expelling pathogenic wind and regulating vital energy, harmonizing the stomach and promoting digestion, as well as relaxing abdominal pain and expelling parasite (Wei et al., 2019; Yuan, 1999).

As known, the occurrence of bolting and flowering (BF) plays a critical role in transiting from vegetative growth to reproductive development in plant life cycle (Kitashiba and Yokoi, 2017). However, the BF significantly reduces the accumulation of metabolites in vegetative organs, which ultimately leads to the lignification of rhizomes and/or roots such as sugar beet (Mutasa-Göttgens et al., 2010), lettuce (Ning et al., 2019), and Chinese cabbage (Wen et al., 2006). Particularly, it is more common that the BF significantly reduces the yield and quality for the rhizomatous AMPs (Zhao et al., 2016). Extensive studies have demonstrated that the BF is regulated by both internal factors (*e.g.,* germplasm resource, seedling size, and plant age) and external factors (*e.g.,* vernalization, photoperiodism, and environmental stresses) (Lincoln and Eduardo, 2010). To date, the BF, especially in the rhizomatous AMPs, has not been effectively controlled (Li et al., 2022b; Zhao et al., 2016).

In order to comprehensively learn about the current status of AMPs, herein, the progress on traditional use, phytochemistry, bolting and flowering, and controlling approaches were summarized. These reviews will provide references for efficient cultivation and quality improvement of AMPs.

2. Materials and methods

All information involved in AMPs was searched on scientific databases (*e.g.,* PubMed, Web of science, Google Scholar, Springer, and CNKI) using the keywords including: Apiaceae plant, traditional use, phytochemistry, bolting and flowering, and lignification. Additional information was collected from ethnobotanical literature focusing on herb from flora of China and local herbal classic literature, such as *Divine Husbandman's Classic of the Materia Medica* (*Shen Nong Ben Cao Jing*), *Compendium of Materia Medica*, *Illustrated Book on Plants*, *Flora of China*, *Collection of National Chinese Herbal Medicine*, and *Pharmacopoeia of the People's Republic of China*. All plants species name were corresponded to in Catalogue of Life China: 2022 Annual Checklist. Chemical structures were drawn using ChemDraw 2021 software.

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3. A tour of Apiaceae medicinal plants (AMPs)

Apiaceae plants have been traditionally used as medicines in China for *ca.* 2400 years (Fig. 1). In 390-278 BC, 3 Apiaceae plants including *Angelica dahurica*, *Ligusticum chuanxiong*, and *Cnidium monnieri* were first recorded as medicines in *Sorrow after Departure* (Wei et al., 2019; Yuan, 1999). With the progress of Chinese civilization, *ca.* 100 Apiaceae plants were historically recorded as medicines. Specifically, 12 AMPs such as *Angelica decursiva*, *Bupleurum chinense*, and *Centella asiatica* were recorded in the known herbal text of China, the *Divine Husbandman's Classic of the Materia Medica* (*Shen Nong Ben Cao Jing*) in 1st-2nd century AD (Shang, 2008); In 1578 and 1848, 24 and 31 AMPs were respectively recorded in the *Compendium of Materia Medica* and *Illustrated Book on Plants* (Li, 2012). In the 21st century, the number of AMPs has been increasing up to 93 species recorded in *Flora of China* in 2002 (Flora Reipublicae Popularis Sinicae, 2002), and 96 species in *Collection of National Chinese Herbal Medicine* in 2014 (Wang, 2014). In recent years, 22 species are recorded in *Pharmacopoeia of the People's Republic of China* (2020); especially, 18 species are used with rhizomes and/or roots (Table 1).

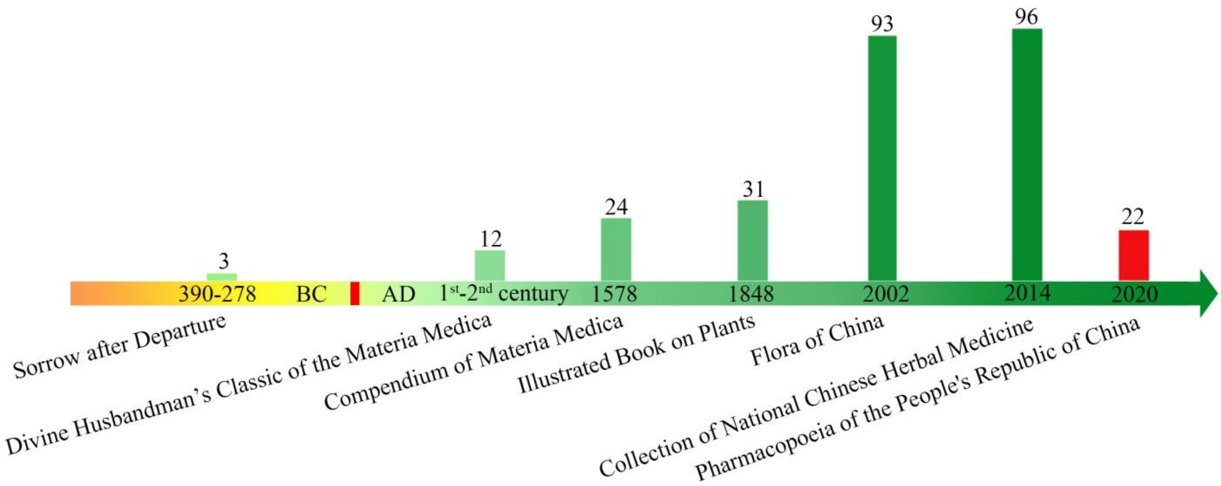

Fig. 1 A tour of Apiaceae medicinal plants

4. Classification of AMPs species

To our best knowledge, a total of 228 AMPs used as TCMs are collected from previously published literatures and books (Table 1). Based on the traditionally used medicinal parts, the 228 AMPs are categorized into 6 classes including: 89 species (11 genera) used with the whole plants (*i.e.*, rhizome and/or root, stem, and leaf), 187 species (31 genera) used with rhizomes and/or roots, 6 species (5 genera) used with stems, 8 species (8 genera) used with leaves, 28 species (10

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genera) used with fruits, and single species (single genus) used with seeds.

Specifically, the 11 genera used with whole plants include: *Bupleurum*, *Centella*, *Conium*, *Coriandrum*, *Eryngium*, *Hydrocotyle*, *Oenanthe*, *Pimpinella*, *Pternopetalum*, *Sanicula*, and *Sium* genera; the 31 genera used with rhizomes and/or roots include: *Angelica*, *Apium*, *Archangelica*, *Bupleurum*, *Carum*, *Changium*, *Chuanminshen*, *Cicuta*, *Conioselinum*, *Daucus*, *Ferula*, *Glehnia*, *Kitagawia*, *Heracleum*, *Hymenidium*, *Kitagawia*, *Kitagawia*, *Levisticum*, *Libanotis*, *Ligusticum*, *Meeboldia*, *Nothosmyrnium*, *Osmorhiza*, *Peucedanum*, *Pimpinella*, *Pternopetalum*, *Saposhnikovia*, Seseli, Seselopsis, and Tongoloa genera; the 5 genera used with stems include: *Aegopodium*, *Coriandrum*, *Foeniculum*, *Ligusticum*, and *Oenanthe*; the 8 genera used with leaves include: *Aegopodium*, *Anethum*, *Angelica*, *Anthriscus*, *Carum*, *Daucus*, *Foeniculum*, and *Ligusticum*; the 10 genera used with fruits include: *Ammi*, *Carum*, *Cnidium*, *Coriandrum*, *Cuminum*, *Cyclorhiza*, *Daucus*, *Pimpinella*, *Trachyspermum*, and *Visnaga* genera; as well as the single genera used with seeds is *Ferula* (Table 1).

5. Traditional uses

As shown in Table 1, distinct traditional uses of the 228 AMPs were recorded. Based on their clinical agents, a total of 72 traditional uses are enriched, with 34 species (*e.g.*, *Angelica apaensis*, *Conium maculatum*, and *Hydrocotyle hookeri*) contributing to the treatment of relieving pain, 22 species (*e.g.*, *Aegopodium alpestre*, *Apium graveolens*, and *Carum carvi*) to the treatment of dispelling wind; and 18 species (*e.g.*, *Conioselinum vaginatum*, *Hydrocotyle sibthorpioides var. batrachium*, and *Ligusticum sinense* Oliv.) to the treatment of eliminating dampness (Fig. 2).

What's more, AMPs were also widely used as ethnodrug in ethnic minority of China. For example, *Carum carvi* L. was used as Tibetan medicine for the treatment of dispelling wind and eliminating dampness, treating cat fever and joint pain (Shen et al., 2010), *Trachyspermum ammi* (Ma et al., 2011a) was used as Uygur medicine for the treatment of eliminating cold damp, dispelling coldness, and promoting digestion; *Angelica acutiloba* was used as Korean nationalities medicine for the treatment of strengthening spleen, enriching blood, stopping bleeding, and promoting coronary circulation (Yao et al., 2018); *Angelica sinensis* was used as Tujia minority medicine for the treatment of enriching the blood, treating dysmenorrheal, and

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relaxing bowel (Fang, 2007); and *Chuanminshen violaceum* was used as geo-authentic medicine of Sichuan province for the treatment of moistening lung melt phlegm, as well as nourishing spleen and stomach (Chen and Peng, 2011).

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1 **Table 1 The list of the 228 Apiaceae medicinal plants (AMPs)**

No.	Plant species	Parts of plant used	Traditional use	Modern pharmacological use	Main chemical uses	References
1	*Aegopodium alpestre* Ledeb.	Stem and leaves	Dispelling wind, relieving pain, and treatment of influenza	Treatment of rheumatic diseases, obesity and hypotensive	Apiole, undecane, and limonene	(Dictionary of Chinese Medicine, 2006; Sun et al., 2009; Zhou et al., 2006)
2	*Ammi majus* L.	Fruits	Treatment of vitiligo	\	Furanocoumarins	(Flora of China, 2002)
3	*Anethum graveolens* L.	Fruits, leaves or whole plant	Treatment of bladder inflammation, liver diseases, and insomnia	Antibacterial, antifungal, antioxidative	Alkaloid, terpenoids, and flavonoids	(Chahal et al., 2017) (Chahal et al., 2017)
4	*Angelica acutiloba* (Siebold & Zucc.) Kitag.	Roots	Treatment of menoxenia and anemia	Hemogenic, analgesic, and sedative activities	Ferulic acid, ligustilide, and angelicide	(Park et al., 2017)
5	*Angelica amurensis* Schischk.	Roots	\	\	α-pinene, limonene, and sabinene	(Wei et al., 2019; Yan et al., 1990)
6	*Angelica anomala* Avé-Lall.	Roots	Dispelling wind, eliminating dampness, and relieving pain	Antioxidative, anti-inflammatory, and antitumor	Isoimperatorin, umbelliferone, and adenosine	(Flora of China, 2002; Sui, 2010; Wu, 1988; Zhou and Zeng, 2019)
7	*Angelica apaensis* R. H. Shan & C. C. Yuan	Roots	Relieving pain, relieving cough and asthma	Bacteriostat, anti-inflammatory, and treatment of headache	Oxypeucedanin, isoimperatorin, and oxypeucedanin hydrate	(Dictionary of Chinese Medicine, 2006; Meng et al., 2008)
8	***Angelica biserrata* (R. H. Shan & C. C. Yuan) C. C. Yuan & R. H. Shan	Roots	Dispelling wind, eliminating dampness, and relieving pain	Anti-tumor, anti-inflammatory, and antioxidant	Coumarins osthole, columbianadin, and volatile oils	(Liu et al., 2020a)
9	*Angelica cartilaginomarginata var. Foliosa* C. C. Yuan & R. H. Shan	Roots	\	\	\	(Wang, 2014)
10	***Angelica dahurica* (Fisch. Ex Hoffm.) Benth. & Hook. F. Ex Franch. & Sav.	Roots	Treatment of acne, erythema, and headache	Protection against sepsis, anti-staphylococcal, and pharmacological activity	Coumarins and furanocoumarins (coumarin, scopoletin, and psoralen)	(Bai et al., 2016; Choi et al., 2008; Lechner et al., 2004; Pharmacopoeia of the People's Republic of China, 2020; Saiki et al., 1971)
11	***Angelica dahurica cv. Hangbaizhi*	Roots	Treatment of headache, toothache, abscess, and furunculosis	Estrogenic, cytotoxic, and anti-inflammatory	Coumarins (isoimperatorin, imperatorin, and phellopterin)	(Pharmacopoeia of the People's Republic of China, 2020; Wei et al., 2016a; Wei et al., 2017b)
12	*Angelica dahurica var. Formosana* (H. Boissieu) Yen	Roots	\	Anti-staphylococca	Falcarindiol	(Saiki et al., 1971; Wei et al., 2016a)
13	***Angelica decursiva* (Miq.) Franch. & Sav.	Roots	A remedy for thick phlegm, asthma, and upper respiratory tract infections	Antioxidant and anti-inflammatory potential	Coumarin derivatives (decursin, decursidin, and nodakenetin)	(Zhao et al., 2012)
14	*Angelica gigas* Nakai	Roots	Treatment of dysmenorrhea, amenorrhea, and menopausal	Anti-platelet effects	Decursin, and decursinol angelate	(Ahn et al., 2008; Lee et al., 2013)
15	*Angelica laxifoliata* Diels	Roots	Dispelling wind, Dispelling wind, and relieving pain	Treatment of wind-damp pain, aching lumbus, and knees	Angelicin, β-sitosterol, and laxifolin	(Flora of China, 2002; Gu et al., 1999; Wu, 1988)
16	*Angelica megaphylla* Diels	Roots	Same as *Angelica sinensis*	Same as *A. Sinensis*	Ferulic acid, ligustilide, and angelol	(Song et al., 2010; Wang, 2018b)
17	*Angelica morii* Hayata	Roots and leaves	Treatment of deficiency-cold in spleen and stomach, cold cough, and toothache	Used for diarrhea caused by deficiency of spleen and for cough caused by weak-ness and chill	Coumarins (imperatorin, isoimperatorin, and phellopterin)	(Sun et al., 2005; Sun et al., 2002; Tang, 1999)
18	*Angelica nitida* H. Wolff	Roots	Nourishing the blood, regulating menstrual disorder, and relieving pain	\	Isoimperatorin, imperatorin, and cnidilin	(Song et al., 2014)
19	*Angelica polymorpha* Maxim.	Roots	Dispelling wind and relieving pain	Treatment of stomachache	Coumarins, sesquiterpenoids, and alkaloid	(Dictionary of Chinese Medicine, 2006; Yang et al., 2013; Zhan, 1994)

20	***Angelica sinensis* (Oliv.) Diels	Roots	Nourishing the blood, regulating menstrual disorder, and relieving pain	Cardio-cerebrovascular, anti-inflammatory, and antioxidant	Ferulic acid, alkylphthalides, and polysaccharides	(Kataki and Kakoti, 2015; Pharmacopoeia of the People's Republic of China, 2020; Upton, 2003)
21	*Angelica sinensis* var. Wilsonii	Roots	Same as *Angelica sinensis*, relieving pain	Same as *Angelica sinensis*	Isoimperatorin, coumarin, and oxypeucedanin	(Zhou and Du, 1982)
22	*Angelica tsinlingensis* K. T. Fu	Roots	\	\	\	(Wei et al., 2019)
23	*Angelica valida* Diels	Roots	\	\	\	(Wei et al., 2019)
24	*Anthriscus nemorosa* (M. Bieb.) Spreng.	Roots	Same as *Peucedanum praeruptorum*	Same as *Peucedanum praeruptorum*	\	(Rao et al., 1995)
25	*Anthriscus sylvestris* (L.) Hoffm.	Roots and leaves	Invigorating spleen and replenishing qi and expelling phlegm	Antitumor, antioxidation, and antisenity	Phenylpropanoids, flavonoids, and steroidal	(Dictionary of Chinese Medicine, 2006; Tan et al., 2017)
26	*Angelica sylvestris* L.	Roots	Relieves rheumatism, sweating, and detoxification	\	Volatile oils (cnidilide, sedanenolide, and ligusti-lide)	(Dictionary of Chinese Medicine, 2006)
27	*Apium graveolens* L.	Whole plant, roots, and rhizome	Dispelling wind, eliminating dampness, and detoxification	Hypertension, hyperlipidemia, and dysuria	Organic acids, apigenin, and volatile oils	(Dictionary of Chinese Medicine, 2006; Liu, 2004; Marongiu et al., 2012)
28	*Archangelica brevicaulisf*	Roots	Same as *Angelica biserrate*	Same as *Angelica biserrate*	Osthol, imperatorin, and archangelicin	(Flora of China, 2002; Zhang et al., 1999)
29	*Bupleurum angustissimum* (Franch.) Kitag.	Roots	\	\	Saikosaponins (a, c, and d), β -terpinene, and β -thujene	(Pan et al., 2002)
30	*Bupleurum aureum* Fisch.	Roots	\	\	Saikosaponin a, saikosaponin c, and saikosaponin d	(Wei et al., 2019; Yang et al., 2008)
31	*Bupleurum bicaule* Helm	Roots	Same as *Bupleurum scorzonerifolium*	Same as *Bupleurum scorzonerifolium*	Saponins (saikosaponin d, prosaikogenin G, and prosaikogenin F), sterols, and phenolic acids	(Flora of China, 2002; Wei et al., 2018; Zhu et al., 2008)
32	*Bupleurum candollei* Wall. Ex DC.	Whole plant	Diminish inflammati and detoxify, expelling wind, and relieving convulsion	\	Saikosaponin and flavonoids	(Flora of China, 2002; Pan et al., 2002)
33	*Bupleurum chaishoui* R. H. Shan & M. L. Sheh	Roots and rhizome	Same as *bupleurum*	Same as *Bupleurum*	Saikosaponin a, saikosaponin c, and saikosaponin d	(Jin et al., 1996)
34	***Bupleurum chinense* DC.	Roots	Treatment of chronic hepatitis, kidney syndrome, and inflammatory diseases	Anti-allergic action, analgesic action, and anti-inflammation effects	Saikosaponin a, saikosaponin c, and saikosaponin d	(Pharmacopoeia of the People's Republic of China, 2020; Zhu et al., 2009a; Zhu et al., 2009b)
35	*Bupleurum chinense* DC. F. Octoradiatum (Bunge) Shan et Sheh	Roots	Same as *bupleurum*	Anti-allergic action, analgesic action, and anti-inflammation effects	Saikosaponin a, saikosaponin c, and saikosaponin d	(Huang et al., 2017a; Ou and Huang, 2021)
36	*Bupleurum chinense* DC. F. Vanheurckii (Muell. -Arg.) Shan et Y. Li	Roots	Same as *bupleurum*	Anti-allergic action, analgesic action, and anti-inflammation effects	Saikosaponin a, saikosaponin c, and saikosaponin d	(Huang et al., 2017a; Ou and Huang, 2021)
37	*Bupleurum commelynoideum var. Flaviflorum* R. H. Shan & Yin Li	Roots or whole plant	Antipyretic-analgesic effect, choleretic, and hepatoprotection	Treating or relieving inflammatory bowel disease	Saikosaponins (a, c, and d), β-pinene, and perillen	(Li et al., 1996; Shih et al., 2013)
38	*Bupleurum densiflorum* Rupr.	Roots	\	\	\	(Huang et al., 2017a)
39	*Bupleurum dielsianum* H. Wolff	Roots	\	\	\	(Huang et al., 2017a)

40	*Bupleurum euphorbioides* Nakai	Roots	\	\	Saikosaponins, perillen, and undecanal	(Pan et al., 2002)
41	*Bupleurum exaltatum M.* Bieb.	Roots	\	\	\	(Ou and Huang, 2021)
42	*Bupleurum falcatum* L.	Roots	\	Treatment of colds and upper respiratory tract infections	Saikosaponin a, saikosaponin c, and saikosaponin d	(Liu et al., 2011b; Ma et al., 2011b; Ou and Huang, 2021)
43	*Bupleurum gansuense* S. L. Pan et Hsu	Roots	\	\	\	
44	*Bupleurum hamiltonii* N. P. Balakr.	Roots or whole plant	Antipyretic-analgesic effect, treatment of chill, and fever alternation	Treatment of stomach pain, dysuria, and cough	Kaerophyllin, isokaerophyllin, and Ethyl caffeic acid	(Feng, 1981)
45	*Bupleurum hamiltonii var. Hamiltonii* / *Bupleurum tenue*	Roots or whole plant	Same as *Bupleurum hamiltonii* N. P. Balakr.	Same as *Bupleurum hamiltonii* N. P. Balakr.	Same as *Bupleurum hamiltonii* N. P. Balakr.	(Zhang et al., 2021)
46	*Bupleurum hamiltonii var. Humile* (Franch.) R. H. Shan & M. L. Sheh	Roots	\	\	\	(Ou and Huang, 2021)
47	*Bupleurum huizei* S. L. Pan sp. Nov.	Roots	\	\	\	(Ou and Huang, 2021)
48	*Bupleurum kaoi* T. S. Liu, C. Y. Chao & T. I. Chuang	Roots	\	Treatment of influenza and fever.	Saikosaponin a and saikosaponin c	(Ou and Huang, 2021)
49	*Bupleurum komarovianum* Lincz.	Roots	Same as *Bupleurum chinense*	Same as *Bupleurum chinense*	Saikosaponins (a, c, and d) and volatile oils (1-caprylene, limonene, and thymol)	(Liu et al., 1993; Tian et al., 1993)
50	*Bupleurum krylovianum Schischk. Ex* Krylov	Roots	\	\	Saikosaponin a, saikosaponin c, and saikosaponin d	(Pan et al., 2002; Yang et al., 2008)
51	*Bupleurum kunmingense* Yin Li & S. L. Pan	Roots	\	Immunomodulatory	Saikosaponins (a, c, and d), cyclohexanone, and 2-methyldodecane	(Pan et al., 2002)
52	*Bupleurum longicaule var. Amplexicaule* C. Y. Wu	Roots	\	\	Saikosaponin a, saikosaponin c, and saikosaponin d	(Ou and Huang, 2021)
53	*Bupleurum longicaule var. Franchetii* H. Boissieu	Roots	\	\	Saikosaponins (a, c, and d), cyclohexanone, and myrcene	(Pan et al., 2002)
54	*Bupleurum longicaule var. Giraldii* H. Wolff	Roots	\	\	Saikosaponins (a, c, and d), narcissin, and rutin	(Pan et al., 2002)
55	*Bupleurum longiradiatum* Turcz.	Roots	Treatment of gout and inflammatory illness	Antiinflammatory and/or antimicrobial activity	Thymol, butylidene phthalide and 5-indolol	(Shi et al., 2010)
56	*Bupleurum luxiense* Yin Li & S. L. Pan	Roots	\	\	Saikosaponins (a, c, and d), n-heptaldehyde, and octanal	(Pan et al., 2002)
57	*Bupleurum malconense* R. H. Shan & Yin Li	Whole plant	Hepatoprotection and antipyretic effect	Acute toxicity	Saikosaponins (a, c, and d), rutin, and quercetin	(Yan et al., 2014; Yan et al., 2019; Yan et al., 2017)
58	*Bupleurum marginatum var. Marginatum*	Whole plant	Hepatoprotection and antipyretic effect	Anti-allergic activity, analgesic action, and anti-inflammatory action	Saikosaponins (a, c, and d), rutin, and quercetin	(Aoyagi et al., 2001; Yan et al., 2014; Yan et al., 2019)
59	*Bupleurum marginatum var. Stenophyllum* (H. Wolff) R. H. Shan & Yin Li	Whole plant	\	\	Saikosaponins (a, c, and d), chikusaikoside I, II, and 2-methylcyclopentanone	(Pan et al., 2002)
60	*Bupleurum marginatum* Wall. Ex DC.	Whole plant and roots	Hepatoprotection and antipyretic effect	Anti-allergic activity, analgesic action, and anti-inflammatory action	Saikosaponins (a, c, and d), rutin, and quercetin	(Aoyagi et al., 2001; Yan et al., 2014; Yan et al., 2019)

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61	*Bupleurum microcephalum* Diels	Whole plant and roots	Hepatoprotection and antipyretic effect	Anti-allergic activity, analgesic action, and anti-inflammatory action	Saikosaponins (a, c, and d), rutin, and quercetin	(Yan et al., 2014; Yan et al., 2019)
62	*Bupleurum petiolulatum var. Tenerum* R. H. Shan & Yin Li	Whole plant	Antipyretic-analgesic effect	Anti-inflammatory	\	(Huang et al., 2017a; Ma et al., 2022)
63	*Bupleurum polyclonum* Yin Li & S. L. Pan	Roots	\	Anticancer	Saikosaponins (a, c, and d), 4'-O-saikosaponin-a, and fenchane	(Pan et al., 2002)
64	*Bupleurum rockii* H. Wolff	Roots	\	\	Saikosaponins (a, c, and d), thymol, and β -guaiene	(Pan et al., 2002)
65	*Bupleurum scorzonerifolium* f. Longiradiatum	Roots	Same as *bupleurum*	Same as *Bupleurum*	Same as *Bupleurum*	(Dictionary of Chinese Medicine, 2006)
66	*Bupleurum scorzonerifolium* f. Pauciflorum	Roots	Same as *bupleurum*	Same as *Bupleurum*	Same as *Bupleurum*	(Dictionary of Chinese Medicine, 2006)
67	***Bupleurum scorzonerifolium* Willd.	Roots	Antipyresis, relieve liver depression and menstrual disorder	Same as *Bupleurum marginatum*	Rutin, quercetin, and kaempferol	(Dictionary of Chinese Medicine, 2006; Pharmacopoeia of the People's Republic of China, 2020)
68	*Bupleurum sibiricum var. Jeholense* (Nakai) Y. C. Chu ex R. H. Shan & Yin Li	Roots	\	\	\	(Wei et al., 2019)
69	*Bupleurum sibiricum* Vest	Roots	Same as *bupleurum*	Same as *Bupleurum*	Aikosaponin a, rutin, and quercetin	(Flora of China, 2002; Guo et al., 2020; Song and Jia, 1992)
70	*Bupleurum sichuanense* S. L. Pan et Hsu.	Roots	\	\	Saikosaponin a, c, and d	(Pan et al., 2002)
71	*Bupleurum smithii* H. Wolff	Roots	Antipyretic-analgesic effect	Anti-inflammatory, immunomodulatory, and anti-hepatic injury	Saponins, volatile oils, and lignans	(Liu et al., 2014)
72	*Bupleurum smithii var. Parvifolium* R. H. Shan & Yin Li	Roots	Relieve liver depression and activate the yang-energy	Anti-inflammatory, immunomodulatory, and antitumor	Volatile oils (falcarinol), saponins (saponins a), and flavonoids	(Zhang et al., 2013)
73	*Bupleurum thianschanicum* Freyn	Roots	\	\	Saikosaponin a, saikosaponin c, and saikosaponin d	(Yang et al., 2008)
74	*Bupleurum triradiatum* Adams ex Hoffm.	Roots	\	\	\	(Wei et al., 2019)
75	*Bupleurum wenchuanense* R. H. Shan & Yin Li	Roots	Same as *bupleurum*	Same as *Bupleurum*	Quercetin-3-*O*-α-*L*-rhamnoside, quercetin, and rutin	(Flora of China, 2002; Yan et al., 2019)
76	*Bupleurum yinchowense* R. H. Shan & Yin Li	Roots	Antipyresis, relieve liver depression, and activate the yang-energy	Same as *Bupleurum*	Aikosaponins (aikosaponin a and aikosaponin d) and volatile oils	(Flora of China, 2002; Li et al., 1996; Li et al., 1997; Liu and Shang, 1994)
77	*Carum buriaticum* Turcz.	Roots	\	\	\	(Li et al., 2022a)
78	*Carum carvi* L.	Roots, fruits, and leaves	Dispelling wind and eliminating dampness, invigorate the stomach, and treatment of heart disease	Anti-bacterial, antioxidant, and antitumor	Volatile oils (carvone, limonene, and dihydrocarvone)	(Dictionary of Chinese Medicine, 2006; Pang and Cui, 2022; Shen et al., 2010)
79	**Centella asiatica* (L.) Urb.	Whole plant	Clearing heat, promoting diuresis, and toxicity	Anti-bacterial, anti-depression andneuroprotection	Triterpenoids (asiaticoside, madecassoside, and asiaticoside B), glycosides and volatile oils (caryophyllene, farnesol, and elemene)	(Pharmacopoeia of the People's Republic of China, 2020; Xiang et al., 2016)
80	***Changium smyrnioides* H.	Roots	Strengthening with tonics, moistening	Immunomodulatory, relieve fatigue,	Polysaccharides (rhamnose,	(Ji et al., 2015; Pharmacopoeia of the

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	Wolff		lung melt phlegm, and calm the liver	and enhance adaptability	arabinose, and xylose), fatty acids (cetylic acid, succinic acid, and tricosanoic acid), and coumarins (phellopterin, isoimperatorin, and Imperatorin)	People's Republic of China, 2020)
81	*Chuanminshen violaceum* M. L. Sheh & R. H. Shan	Roots	Moistening lung melt phlegm, harmonize the stomach, and engender liquid	Antioxidant, enhancing immunity, and antimutation	Polysaccharides, coumarins, and flavonoids	(Chen and Peng, 2011; Chen et al., 2008; Fan et al., 2017)
82	*Cicuta virosa* L.	Roots and rhizome	Expelling phlegm and detoxification	Treatment of osteomyelitis, gout, and rheumatism	P-cymene, cicutoxine, and L-limonene	(Wang, 2014; Wang and Feng, 2000)
83	**Cnidium monnieri* (L.) Spreng.	Fruits	Expelling wind, relieving convulsion, and Impotence	Antibacterial, antiviral, and antimutagenesis	Osthole, limonene, and cnidimoside A	(Pharmacopoeia of the People's Republic of China, 2020; Tian et al., 2020)
84	*Cnidium officinale*	Roots	Same as *Cnidium monnieri*	Same as *Cnidium monnieri*	\	(Wei et al., 2019)
85	*Conioselinum acuminatum* (Franch.) Lavrova	Roots	\	\	Sabinene, α-pinene, and aromadendrene	(Zhao, 2016)
86	*Conioselinum anthriscoides* '*Fuxiong*'	Roots	\	\	β-bergamotene	(Zhao, 2016)
87	*Conioselinum tenuisectum* (H. Boissieu) Pimenov & Kljuykov	Roots	\	\	\	(Wang et al., 2022)
88	*Conioselinum vaginatum* (Spreng.) Thell.	Roots	Dispelling wind, eliminating dampness, and relieving pain	Treatment of common cold due to wind-cold, headache and gastro spasm	Coumarins (diligustilide, bergapten, and isopimpinellin), steroid (pregnenolone, stigmast-4-en-3,6-dione, β-sitosterol, and daucosterol), organic acids (coniselin, ferulic acid, and palmitic acid)	(Dictionary of Chinese Medicine, 2006; Xue et al., 1996)
89	*Conium maculatum* L.	Whole plant	Relieving pain and relieving muscular spasm	Treatment of cancer	Coniine, N-methyl-coniine, conhydrine 2-(1-hydroxypropyl)-piperidine	(Flora of China, 2002; Ran, 1993; Vetter, 2004)
90	*Coriandrum sativum* L.	Whole plant	Invigorate the stomach and promoting eruption	Antibacterial, antifungal, and antioxidant activities	Fatty oil (petroselinic acid, linoleic acid, oleic acid, and palmitic acid)	(Dictionary of Chinese Medicine, 2006; Mandal and Mandal, 2015)
91	*Cryptotaenia japonica* Hassk.	Whole plant	Treatment of weakness, urinary closure, and swelling	Antioxidant, protect liver, and anticancer	Friedelin, stigmasterol, and apigenin	(Dictionary of Chinese Medicine, 2006; Li and Niu, 2012; Lu et al., 2017)
92	*Cuminum cyminum* L.	Fruits	Treatment of indigestion and stomach cold abdominal pain	Antibacterial, antioxidative, and radical-scavenging properties	Volatile oils (α-pinene, 1,8-cineole, and linalool)	(Dictionary of Chinese Medicine, 2006; Gachkar et al., 2007)
93	*Cyclorhiza peucedanifolia* (Franch.) Constance	Fruits	Enriching the blood, activating blood, and regulating menstrual disorder	\	\	(Zhong et al., 2016)
94	*Daucus carota* L.	Fruits	Treatment of ascariasis, enterobiasis, and tapeworm disease	Insecticide, anti-bacterial, and anti-cance	Volatile oils (α-pinene, isophorone oxide, and β-bisabolene), sesquiterpeniods, and flavonoids (luteolin, mannose, and quercetrin)	(Cui et al., 2020; Pharmacopoeia of the People's Republic of China, 2020)
95	*Daucus carota var. Carota*	Fruits	Treatment of ascariasis, enterobiasis, and tapeworm disease	Insecticide, anti-bacterial, and anti-cance	Volatile oils (α-pinene, isophorone oxide, and β-bisabolene), sesquiterpeniods, and flavonoids (luteolin, mannose, and quercetrin)	(Cui et al., 2020; Pharmacopoeia of the People's Republic of China, 2020)
96	*Daucus carota var. Sativus* Hoffm.	Roots	Strengthening spleen, treatment of dyspepsia, and chronic dysentery	Enhancing immunity, anticancer, and prevents aging	Carotene, (1R)-α-pinene, and β-carotene	(Dictionary of Chinese Medicine, 2006; Wu et al., 2006)

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97	*Eriocycla albescens* (Franch.) H. Wolff	Whole plant	\	\	\	(Wei et al., 2019)
98	*Eryngium foetidum* L.	Whole plant	Diuresis, treatment of dropsy, and snakebite	Baceriostasis activity, diminish inflammati, and detumescence	Lanolin alcohol, carotene, and *n*-nonyl aldehyde	(Dictionary of Chinese Medicine, 2006; Guan et al., 2013)
99	*Ferula bungeana* Kitag.	Whole plant and seeds	Heat-clearing and detoxifying, relieving pain and expelling phlegm, and arresting coughing	Treatment of cold, bronchopneumonia, and pulmonary tuberculosis	Anisole, *d*-fenchone, and limonen	(Dictionary of Chinese Medicine, 2006; Sun et al., 2003b)
100	*Ferula caspica* M. Bieb.	Roots and resin	Eliminating stagnated food, disintegrating masse, and insecticide	Toxicity effect	Umbelliprenin, farnesyl alcohol, and umbelliferone	(Yang, 2018)
101	*Ferula conocaula* Korovin	Resin, roots, and rhizome	Eliminating stagnated food, insecticide, treatment of abdominal mass, and a lump in the abdomen	Anticancer and treatment of influenza	Umbelliprenin, fezelol, and feterin	(Yang, 2018)
102	*Ferula feruloides* (Steud.) Korovin	Roots and resin	Treatment of chilliness, and pain of the heart and abdomen	Insecticidal, bacteriostatic and anti-tumor	Volatile oils (α-pinene, farnesene and toluene)	(Medicinal Flora of Xinjiang, 1977; Yang et al., 2020)
103	***Ferula fukanensis* K. M. Shen	Resin	Eliminating stagnated food, relieve dyspepsia and insecticide	Treatment of stomach disease, rheumatism and joint pain	Ferulic acid, guaiol and ethyl-p-hydroxybenzoate	(Aybek et al., 2018; Dictionary of Chinese Medicine, 2006; Li et al., 2012; Pharmacopoeia of the People's Republic of China, 2020; Zhang et al., 2007)
104	*Ferula jaeschkeana* Vatke	Resin of overground part	Eliminating stagnated food, insecticide, treatment of tumour, wound, and peptic ulcer	Jaeschkeanadiol, α-pinene and β-pinene	Antifertility	(Yang, 2018)
105	*Ferula krylovii* Korovin	Resin	Eliminating stagnated food and insecticide	\	fekrynol, ferukrin and fekrynol acetate	(Yang, 2018)
106	*Ferula lehmannii* Boiss.	Resin	Detoxification, deodorize, and insecticide	Treatment of gastropathy, rheumatism and arthralgia	Lehmannolone, sinkianone, and lehmannolone A	(Flora of China, 2002; Li et al., 2010)
107	*Ferula moschata* (Reinsch) Koso-Pol.	Root	Sedative, spasmolysis, and treatment of hysteria	Suppress the replication of human immunodeficiency virus in H9 lymphocytes and suppress the production of cytokine	fezelol, fesumtuorin A and fesumtuorin B	(Yang, 2018)
108	*Ferula olivacea* (Diels) H. Wolff ex Hand.-Mazz.	Resin	Wind-heat dispersing, expelling phlegm, and arresting coughing	\	\	(Flora of China, 2002)
109	***Ferula sinkiangensis* K. M. Shen	Resin	Eliminating stagnated food, detoxification, and insecticide	Antioxidant, antitumor, and antiviral	Ferulic acid, fekrynol, and lehmannolone	(Flora of China, 2002; Huang et al., 2017b; Lai and Yang, 2022; Pharmacopoeia of the People's Republic of China, 2020)
110	*Ferula songarica* Pall. Ex Schult.	Resin and whole plant	Eliminating stagnated food and insecticide	\	2，4-dihydroxylacetophenone, 3，3'，4，4'-biphenyltetracarboxylic acid, and Δ^3-carene	(Yang et al., 2006)
111	*Ferula teterrima* Kar. & Kir.	Resin	Eliminating stagnated food, and insecticide	Treatment of malaria and dysentery	Sesquiterpene coumarin, badrakemin, and badrakemin acetate	(Yang et al., 2006)
112	**Foeniculum vulgare* Mill.	Fruits, roots, stems, and leaves	Dispelling wind, relieving pain, and harmonize the stomach	Bacteriostat, anti-inflammatory, and antianxiety	Trans-anethole, estragole, and anisaldehyde	(Dictionary of Chinese Medicine, 2006; Pharmacopoeia of the People's Republic of China, 2020; Su et al., 2022)
113	***Glehnia littoralis* F. Schmidt ex Miq.	Roots	Heat-clearing and detoxifying, diminish inflammation, and expelling phlegm and arresting coughing	Anti-inflammatory, bacteriostat, and antitumor	Phenyllactic acid, catechol, and quercetin	(Pharmacopoeia of the People's Republic of China, 2020; Ren et al., 2022)
114	*Hansenia oviformis* (R. H.	Rhizome	Treatment of rheumatic arthralgia, cold	\	\	(Flora of China, 2002)

	Shan) Pimenov & Kljuykov		due to wind-cold, and headache			
115	*Heracleum barmanicum* Kurz	Roots	Treatment of cold abdominalgia	\	\	(Flora of China, 2002)
116	*Heracleum candicans* Wall. Ex DC.	Roots	Dispelling wind, eliminating dampness, and relieving pain	Treatment of cold headache and headache	Bergapten, heraclenin, and imperatorin	(Dictionary of Chinese Medicine, 2006; Gao et al., 2015)
117	*Heracleum dissectifolium* K. T. Fu	Roots	Dispelling wind, eliminating dampness, and relieving pain	\	\	(Flora of China, 2002)
118	*Heracleum fargesii* H. Boissieu	Roots	\	\	\	(Wang, 2014)
119	*Heracleum franchetii* M. Hiroe	Roots and rhizome	\	\	\	(Du, et al., 2022; Zhao et al., 2004)
120	*Heracleum hemsleyanum*	Roots and rhizome	Dispelling wind, eliminating dampness, and relieving pain	Antioxidative, anti-inflammatory, and antitumor	Β-pinene, α-pinene, and (1S)-6,6-dimethyl-2-methylene-bicyclo[3.1.1] heptane	(Ma et al., 2005a; Wu, 1988; Zhang et al., 2005a; Zhou and Zeng, 2019)
121	*Heracleum hemsleyanum* Diels	Roots and rhizome	Dispelling wind, eliminating dampness, and relieving pain	Antioxidative, anti-inflammatory, and antitumor	Osthole, columbianadin, and columbianetin	(Wu, 1988; Zhou and Zeng, 2019)
122	*Heracleum henryi* H. Wolff	Roots	Clearing and activating the channels and collaterals, relieving pain, and scattered stasis	\	Turgeniifolin B, turgeniifolin C, and bergapten	(Sun, 1982)
123	*Heracleum millefolium var. Millefolium*	Roots	Detumescence, disintegrate masse, and treatment of leprosy	\	\	(Du, et al., 2022; Zhao et al., 2004)
124	*Heracleum moellendorffii* Hance	Roots and rhizome	Clearing and activating the channels and collaterals, relieving pain, and scattered stasis	Baceriostasis activity	Β-pinene, α-pinene, and pentadecane	(Feng et al., 2002; Ma et al., 2005a; Sun, 1982; Zhang et al., 2006)
125	*Heracleum oreocharis* H. Wolff	Roots	\	\	\	(Zhao et al., 2004)
126	*Heracleum rapula* Franch.	Roots	Clearing and activating the channels and collaterals, relieving pain, and scattered stasis	Bacteriostat, treatment of asthma, and chronic bronchitis	Ostholce, marmesin, and imperatorin	(Chinese Traditional Medicine, 1982; Dictionary of Chinese Medicine, 2006; Sun, 1982)
127	*Heracleum scabridum* Franch.	Roots and fruits	Treatment of common cold due to wind-cold, headache, and cough asthma	\	Heraclenol, oxypeucedanin-hydrate, and byakangelicin	(Madica, 1999; Sun et al., 1978; Wei et al., 2017a)
128	*Heracleum souliei* H. Boissieu	Roots	\	\	Bergapten	(Gao et al., 2004; Zhao et al., 2004)
129	*Heracleum stenopterum* Diels	Roots	Treatment of cold and rheumatism	\	Bergapten, isopimpinellin, and sphondin	(Flora of China, 2002; Lin et al., 1993)
130	*Heracleum tiliifolium* H. Wolff	Roots	Dispelling wind, eliminating dampness, and relieving pain	\	\	(Flora of China, 2002)
131	*Heracleum vicinum* H. Boissieu	Roots	Same as *Notopterygium incisum*	\	\	(Du, et al., 2022; Zhao et al., 2004)
132	*Heracleum wenchuanense* F. T. Pu & X. J. He	Roots	\	\	\	(Zhao et al., 2004)
133	*Heracleum wolongense* F. T. Pu & X. J. He	Roots	\	\	\	(Wei et al., 2019; Zhao et al., 2004)
134	*Heracleum yungningense* Hand.-Mazz.	Roots and rhizome	Treatment of waist and knee pain, limb spasm, and leucoderma	\	Pimpinellin, angelicin, and isobergapten	(Rao et al., 1993; Wu, 1988)
135	*Hydrocotyle himalaica* P. K. Mukh.	Whole plant	Heat-clearing, detoxifying, and eliminating dampness	\	Asiaticoside, madecassoside, and quercetin	(Dong et al., 2012; Xiong et al., 2019)

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136	*Hydrocotyle hookeri subsp. Chinensis* (Dunn ex R. H. Shan & S. L. Liou) M. F. Watson & M. L. Sheh	Whole plant	Relieving pain, diuresis, and removing dampness	Antiviral, antitumor, and anti-bacterial	Flavonoids, triterpenes, and volatile oils, *e.g.*, B-carotene	(Flora of China, 2002; Madica, 1999; Xiong et al., 2019)
137	*Hydrocotyle nepalensis* Hook.	Whole plant	Clearing heat and promoting diuresis, dissolving stasis, and hemostasis and detoxicate	Antiviral, antitumor, and anti-bacterial	Flavonoids, triterpenes, and volatile oils	(Flora of China, 2002; Xiong et al., 2019)
138	*Hydrocotyle sibthorpioides* Lam.	Whole plant	Heat-clearing, diuresis, and detumescence	Anti-ulcer, antilipemic activity, and antiviral	Quercetin, isorhamnetin, and asiaticoside	(Xiong et al., 2019; Xu et al., 2013)
139	*Hydrocotyle sibthorpioides var. Batrachium* (Hance) Hand.-Mazz. Ex R. H. Shan	Whole plant	Heat-clearing and detoxifying, eliminating dampness, and diuresis	Anti-ulcer, spasmolysis, and anti-inflammatory	Flavonoids, volatile oils, *e.g.*, Benzene propane nitrile, phytol, and caryophyllene oxide	(Flora of China, 2002; Handbook of Effective Components of Plant Medicine, 1986; Kang et al., 2003)
140	*Hydrocotyle wilfordii* Maxim.	Whole plant	As *Hydrocotyle nepalensis* Hook.	As *Hydrocotyle nepalensis* Hook.		
141	*Hymenidium chloroleucum* (Diels) Pimenov & Kljuykov	Roots or whole plant	Regulating flow of qi, invigorating stomach, and activating blood	Anti-inflammatory, analgesia, and nutritious function	Nobiletin, falcarindiol, and isoliquiritingenin	(Dictionary of Chinese Medicine, 2006; He and Wang, 2018; Yuan et al., 2012)
142	*Hymenidium davidii* (Franch.) Pimenov & Kljuykov	Roots	\	\	\	(Zhao et al., 2006)
143	*Hymenidium delavayi* (Franch.) Pimenov & Kljuykov	Roots	\	\	\	(Liu et al., 2002; Wei et al., 2019)
144	*Hymenidium lindleyanum* (Klotzsch) Pimenov & Kljuykov	Roots	Treatment of hypertensive, coronary heart disease, and altitude stress	\	bergapten, isoimperatorn, and oxypeucedanin	(Li et al., 2002)
145	*Kitagawia formosana* (Hayata) Pimenov	Roots	\	\	\	(Wei et al., 2019)
146	*Kitagawia macilenta* (Franch.) Pimenov	Roots	Expelling phlegm	\	\	(Liu et al., 1997)
147	*Kitagawia terebinthacea* (Fisch. Ex Trevir.) Pimenov	Roots	Cleaning heat and expelling wind, alm the adverse-rising energy, and expelling phlegm	Treatment of cold and cough, bronchitis, and cough during pregnancy	Isoepoxybuterixin	(Dictionary of Chinese Medicine, 2006)
148	*Levisticum officinale* W. D. J. Koch	Roots	Diuresis, invigorate the stomach, and expelling phlegm	Inhibition of rhythmic uterine contractions, Scavenging oxygen free radicals, and anti- lipid peroxidation	Ligustilide, α-phellandrene, and β-phellandrene	(Dictionary of Chinese Medicine, 2006; Wang and Hu, 2011)
149	*Libanotis buchtormensis* (Fisch.) DC.	Roots	Divergent wind chill, dispel wind-damp, and relieving pain	Bacteriostat, treatment of common cold due to wind-cold, generalized pain, and cough	Falcarinone, isoimperatorin, and xanthotoxin	(Dictionary of Chinese Medicine, 2006; Ge et al., 2015)
150	*Libanotis iliensis* (Lipsky) Korovin	Roots	Expel wind-cold pathogens, thermolysis, and relieving pain	Treatment of common cold due to wind-cold and rheumatic arthritis	Archangelin and iliensin	(Dictionary of Chinese Medicine, 2006)
151	*Libanotis lancifolia* K. T. Fu	Roots	Divergent wind chill, dispel wind-damp, and relieving pain	Bacteriostat, treatment of common cold due to wind-cold, generalized pain, and cough	Falcarinone, isoimperatorin, and xanthotoxin	(Dictionary of Chinese Medicine, 2006; Ge et al., 2015)
152	*Libanotis laticalycina* R. H. Shan & M. L. Sheh	Roots	Dispelling wind, antispasmodic, and relieving pain	Analgesia, sedation, and anti-inflammatory	Octanal, hexanal, and 2-penty-furan	(Flora of China, 2002; Tang et al., 1992; Wang and Lou, 1988)
153	*Libanotis seseloides* (Fisch. & C. A. Mey. Ex Turcz.)	Roots	Eliminating dampness, activating spleen, and promote blood circulation	Treatment of damobstruction, dysentery, and sore	Edultin	(Dictionary of Chinese Medicine, 2006)

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	Turcz.					
154	*Libanotis sibirica* (L.) C. A. Mey.	Roots	\	\	\	(Wei et al., 2019)
155	*Libanotis spodotrichoma* K. T. Fu	Roots	Divergent wind chill, dispel wind-damp, and relieving pain	Bacteriostat, treatment of common cold due to wind-cold, generalized pain, and cough	Falcarinone, isoimperatorin, and xanthotoxin	(Dictionary of Chinese Medicine, 2006; Ge et al., 2015)
156	*Ligusticopsis brachyloba* (Franch.) Leute	Roots	Sudation, relieving pain, and expelling wind	Treatment of headache dizziness, arthralgia, and tetanus	A-pinene, β-pinene, and sabinene	(Huang and Pu, 1990; Illustrated Handbook for Natural Medicine in Yunnan, 2007; Li and Qiu, 2020)
157	*Ligusticopsis daucoides* (Franch.) Lavrova & Kljuykov	Roots	\	\	\	(Wang et al., 2022; Wei et al., 2019)
158	*Ligusticopsis likiangensis* (H. Wolff) Lavrova & Kljuykov	Roots	\	\	\	(Wang et al., 2022; Wei et al., 2019)
159	***Ligusticum chuanxiong* Hort.	Roots and rhizome	Activating blood, relieving pain, and Dispelling wind	Anti-inflammatory, antioxidant, and antitumor	Volatile oil (abietene), alkaloid (tetramethylpyrazine), and polysaccharide (glucose)	(Dictionary of Chinese Medicine, 2006; Pharmacopoeia of the People's Republic of China, 2020; Zhang et al., 2020)
160	***Ligusticum jeholense* Nakai et Kitag.	Roots and rhizome	Dispelling wind, dispersing cold, and eliminating dampness	Anti-inflammatory, sedation, and anti-ulcer	Ferulic acid, isoferulic acid, and daucosterol	(Dictionary of Chinese Medicine, 2006; Lu et al., 2010; Pharmacopoeia of the People's Republic of China, 2020; Zhang and Shen, 2006)
161	*Ligusticum pteridophyllum* Franch.	Roots	Dispelling wind, relieving pain, and eliminating dampness	Treatment of cold due to wind-cold, headache, and migraine	Asaricin, β-sitosterol, and daucosterol	(Rao et al., 1991; Wu, 1988)
162	***Ligusticum sinense* Oliv.	Roots, rhizome, and tuber	Expel wind-cold pathogens, eliminating dampness, and relieving pain	Anti-inflammatory, central inhibitory, and anti-thrombotic effect	3-butylphthalide, opthalonide, and neopthalonide	(Pharmacopoeia of the People's Republic of China, 2020; Tang, 2011)
163	*Ligusticum tenuissimum* (Nakai) Kitagawa	Roots and rhizome	Same as *ligusticum sinense* Oliv. Divergent wind chill, treatment of wind-cold headache, and diarrhoea.	Analgesia and sedation	Ferulic acid	(Dictionary of Chinese Medicine, 2006; Wang et al., 1991; Wang et al., 2022b)
164	*Meeboldia delavayi* (Franch.) W. Gou & X. J. He	Roots	Treatment of cold, fever, headache	\	\	(Flora of China, 2002)
165	*Nothosmyrnium japonicum var. Japonicum*	Root	Sedation and analgesia	Sedation and analgesia	\	(Flora of China, 2002)
166	*Nothosmyrnium japonicum var. Sutchuensis* H. Boissieu	Roots	Sedation and analgesia	Sedation and analgesia	\	(Flora of China, 2002)
167	***Notopterygium franchetii* H. De Boiss.	Roots and rhizome	Divergent wind chill, dispelling wind, and eliminating dampness	Anti-inflammatory, analgesia, and antiviral	Nodakenin, ferulic acid, and bergamot lactone	(Pharmacopoeia of the People's Republic of China, 2020; Tang et al., 2018; Zhang, 2015)
168	***Notopterygium incisum* Ting ex H. T. Chang	Roots and rhizome	Divergent wind chill, dispelling wind, and eliminating dampness	Anti-inflammatory, analgesia, and antiviral	Nodakenin, notopterol, and isoimperatorin	(Pharmacopoeia of the People's Republic of China, 2020; Zhang, 2015)
169	*Oenanthe benghalensis* Benth. & Hook.	Roots and whole plant	Same as *Oenanthe javanica* (Blume) DC.	Same as *Oenanthe javanica* (Blume) DC.	\	(Wang, 2014)
170	*Oenanthe javanica* (Blume) DC.	Roots and whole plant	Heat-clearing, detoxification, and removing liver-fire	Enhancing immunity, antiarrhythmic, and hypoglycemic	Phytic acid, γ-terpinene, and caryophyllene	(Dictionary of Chinese Medicine, 2006; Guo et al., 2017)
171	*Oenanthe linearis subsp. Rivularis* (Dunn) C. Y. Wu & F. T. Pu	Roots and whole plant	Same as *Oenanthe javanica* (Blume) DC.	Same as *Oenanthe javanica* (Blume) DC.	\	(Wang, 2014)

172	*Osmorhiza aristata var. Laxa* (Royle) Constance & R. H. Shan	Roots	Divergent wind chill, sudation, and relieving pain	\	\	(Flora of China, 2002)
173	*Ostericum citriodorum* (Hance) C. C. Yuan & R. H. Shan	Roots and whole plant	Activating blood, dissolving stasis, and dispelling wind	Expectorant, anti-inflammatory, and bacteriostat	Isoapiole, panaxynol, and myristicin	(Dictionary of Chinese Medicine, 2006; Li et al., 2020c; Tian et al., 1989; Zhang et al., 2009)
174	*Ostericum grosseserratum* (Maxim.) Kitag.	Roots	Activating spleen, dispersing cold, and invigorating spleen and replenishing qi	\	Octanal, β-pinene, and myristic acid	(Flora of China, 2002; Xue et al., 1995; Xue et al., 1992)
175	*Ostericum sieboldii* (Miq.) Nakai	Roots	\	\	\	(Asgar, 2013; Sousa et al., 2021; Wang et al., 2020)
176	*Peucedanum dielsianum* Fedde ex H. Wolff	Roots and rhizome	Relieving pain, dispelling wind, and eliminating dampness	\	Isoimperatorin, phellopterin, and 9-octadecenoic acid	(Dictionary of Chinese Medicine, 2006; Ji et al., 1999; Yan et al., 1988)
177	*Peucedanum dissolutum* (Diels) H. Wolff	Roots	\	\	\	(Wei et al., 2019)
178	*Peucedanum harry-smithii var. Subglabrum*	Roots	Same as *Peucedanum praeruptorum*, alleviate asthma, reducing phlegm, and heatelimination	Treatment of bronchitis, hypertensive, and coronary heart disease	Psoralen, bergapten, and xanthotoxin	(Kong et al., 1991; Li et al., 2009a; Shi and Kong, 2005; Song et al., 1994)
179	*Peucedanum japonicum* Thunb.	Roots	Clearing heat, relieving cough, and diuresis	Antipyresis, analgesia, and anti-inflammatory	Peucedanol, umbelliferone, and β-pinene	(Dictionary of Chinese Medicine, 2006; Li et al., 2015; Xu and Li, 2016)
180	*Peucedanum ledebourielloides* K. T. Fu	Roots	\	\	\	(Wang et al., 2020; Wei et al., 2019)
181	*Peucedanum longshengense* R. H. Shan & M. L. Sheh	Roots	\	\	\	(Wei et al., 2019)
182	*Peucedanum mashanense* R. H. Shan & M. L. Sheh	Roots	Expelling phlegm	\	\	(Liu et al., 1997)
183	*Peucedanum medicum* Dunn	Roots	Expelling phlegm, *alleviating asthma* and cough, and arresting convulsion	Anticoagulation, antioxidative, and antibacterial	2-methoxy-4-vinylphenol, *p*-menthan-1-ol, and *cis*-α-bisabolene	(Barot et al., 2015; Dictionary of Chinese Medicine, 2006; Lei et al., 2016)
184	*Peucedanum medicum var. Gracile* Dunn ex R. H. Shan & M. L. Sheh	Roots and rhizome	Expelling phlegm, *alleviating asthma* and cough, and arresting convulsion	Anticoagulation, antioxidative, and antibacterial	Isoimperatorin, phellorerin, and bergapten	(Barot et al., 2015; Dictionary of Chinese Medicine, 2006; Huang et al., 2000)
185	*Peucedanum medicum var. Medicum*	Roots and rhizome	Expelling phlegm, *alleviating asthma* and cough, and arresting convulsion	Anticoagulation, antioxidative, and antibacterial	2-methoxy-4-vinylphenol, *p*-menthan-1-ol, and *cis*-α-bisabolene	(Barot et al., 2015; Dictionary of Chinese Medicine, 2006; Lei et al., 2016)
186	***Peucedanum praeruptorum* Dunn	Roots	Divergent wind, clearing heat, and reducing phlegm	Anticoagulation, antioxidative, and anticancer	Praeruptorin A, praeruptorin B, and scopoletin	(Pharmacopoeia of the People's Republic of China, 2020; Song et al., 2021)
187	*Peucedanum shanianum* F. L. Chen & Y. F. Deng	Roots	Relieving asthma, expelling phlegm, and spasmolysis	Anti-inflammatory, antiallergic, and anti-ulcer	Sinodielides A, deltoin, and (+)-pareruptorin A	(Dai et al., 1995; Rao et al., 2006; Rao et al., 1990; Yu et al., 1995)
188	*Peucedanum turgeniifolium* H. Wolff / *Peucedanum pulchrum*	Roots and whole plant	Expelling phlegm, antibechic, and dispersing wind-heat	Smooth muscle spasmolysis	Turgenifolin A, turgenifolin B, and bergapten	(Dictionary of Chinese Medicine, 2006; Rao et al., 1997; Yu et al., 1995)
189	*Peucedanum wawrae* (H. Wolff) S. W. Su ex M. L. Sheh	Roots	Antibechic and expelling phlegm	Analgesia, sedation, and anti-inflammatory	Peucedanocoumarin, d-laserpitin, and bergapten	(Flora of China, 2002; Wang et al., 2020; Wu et al., 2000)
190	*Peucedanum wulongense* R. H. Shan & M. L. Sheh	Roots	\	\	\	(Wei et al., 2019)
191	*Phlojodicarpus sibiricus*	Roots	\	\	\	(Wei et al., 2019)

	(Steph. Ex Spreng.) Koso-Pol.					
192	*Physospermopsis alepidioides* (H. Wolff & Hand.-Mazz.) R. H. Shan	Roots	\	\	\	(Wei et al., 2019)
193	*Physospermopsis delavayi* (Franch.) H. Wolff	Roots	\	\	\	(Wei et al., 2019)
194	*Pimpinella anisum* L.	Mature fruits	Warming meridian, analgesia, and diuresis	Treatment of paralysis, facial paralysis, and migraine	Anisaldehyde, anisole, and total flavonoids, *e.g.*, E)-anethole	(Abuaini et al., 2013; Benelli et al., 2017; Chinese Materia Madica, 2005; Chinese Medical Encyclopedia Uyghur Traditional Medicine, 2005; R.K.Y.M., 1993)
195	*Pimpinella candolleana* Wight & Arn.	Roots or whole plant	Warming spleen and stomach for dispelling cold, relieving pain, and expelling wind	Relieving muscular spasm, antiviral, and antibacterial	A-zingiberene, pregeijerene, and β-elemene	(Dictionary of Chinese Medicine, 2006; Sun and Sheng, 1996; Wei et al., 2005; Zhao et al., 2007a)
196	*Pimpinella coriacea* (Franch.) H. Boissieu	Whole plant	Warming spleen and stomach for dispelling cold, dispelling wind and eliminating dampness, and activating blood	\	\	(Hu et al., 2012)
197	*Pimpinella diversifolia* DC.	Whole plant	Expelling phlegm, activating blood, relieving pain, and removing toxicity for detumescence	Anti-inflammatory, antitumor, and antituberculous	1H-benzocycloheptene, sesquiphellandrene, and β-chamigrene	(Dong and Zhao, 1991; Dong et al., 2021a; Xu et al., 2012)
198	*Pimpinella diversifolia var. Diversifolia*	Roots or whole plant	Invigorating stomach, dispersing accumulations, and antidiarrheic	Anti-inflammatory, antitumor, and antituberculous	1H-benzocycloheptene, sesquiphellandrene, and β-chamigrene	(Dictionary of Chinese Medicine, 2006; Dong and Zhao, 1991; Dong et al., 2021a; Xu et al., 2012)
199	*Pleurospermopsis bicolor* (Franch.) Jing Zhou & J. Wei	Whole plant	Warming spleen and stomach for dispelling cold, benefiting qi and nourishing blood, and coordinating yin and yang	Hypotensive, antilipemic, and modulates and improves cellular immunity	Chlorogenic acid, isochlorogenic acid A, and apigenin-7-*O*-β-D-glucuronopyranoside	(Cui et al., 2019; Jin and Wang, 2008; Liu et al., 2020)
200	*Pleurospermum aromaticum* W. W. Sm.	Whole plant	\	\	\	(Wei et al., 2019)
201	*Pimpinella thellungiana* H. Wolff	Roots or whole plant	Warming spleen and stomach for dispelling cold, benefiting qi and nourishing blood, and coordinating yin and yang	Hypotensive, hypolipidemic, and modulates, and improves cellular immunity	Protocatechuic acid, gallic acid and neochlorogenic acid	(Cui et al., 2019; Huanglong county leading group of prevention and control of endemic diseases in Yan 'an region, 1972; Jin and Wang, 2008; Liu et al., 2020b; Wang et al., 1986)
202	*Pleurospermum giraldii* Diels	Whole plant and seeds	Warming spleen, digesting food, and checking vaginal discharge	Inhibition of smooth muscle contraction and release intestinal smooth muscle spasm	Carvone, n-triactanol, and γ-sitosterol	(Dictionary of Chinese Medicine, 2006; Liu et al., 1998; Zhang, 2000; Zhang et al., 1998)
203	*Pleurospermum rivulorum* (Diels) K. T. Fu & Y. C. Ho	Root or whole plant	Tonifying the kidney	\	\	(Wei et al., 2019; Zhong et al., 2016)
204	*Pternopetalum leptophyllum* (Dunn) Hand.-Mazz.	Whole plant	\	\	\	(Flora of China, 2002)
205	*Pternopetalum vulgare var. Vulgare*	Roots or whole plant	Treatment of lumbago	\	\	(Dictionary of Chinese Medicine, 2006)
206	*Sanicula astrantiifolia* H. Wolff ex Kretschmer	Whole plant	Tonifying the kidney and lung, treating tuberculosis, and kidney vacuity lumbar pain	Antioxidative, antibacterial, and bacteriostat	Total flavonoids, rutin, and polysaccharides	(Chinese Herbal Medicine in Yunnan, 1971; Liu et al., 2016; Liu et al., 2011a)

207	*Sanicula caerulescens* Franch.	Whole plant	Expelling wind, melting phlegm, and promoting blood circulation for regulating menstruation	Expectorant, antibechic, and anti-inflammatory	Angelicin, isoferulaldehyde, and 12-hydroxybakuchiol	(Dictionary of Chinese Medicine, 2006; Xu et al., 2015; Zhou et al., 2005)
208	*Sanicula chinensis* Bunge	Whole plant	Detoxification, hemostasis, and treatment of throat pain	Antiviral	\	(B, 2022; Karagoz et al., 1997; Madica, 1999; Turan and Kuru, 1996)
209	*Sanicula elata* Buch.-Ham. Ex D. Don	Whole plant	Same as *Sanicula lamelligera*	Antiviral	Oleanane saponins, saponins, and microelement	(B, 2022; Hiller et al., 1968; Karagoz et al., 1997; Legin et al., 2018; Matsushita et al., 2004; Turan and Kuru, 1996)
210	*Sanicula lamelligera* Hance	Whole plant	Expelling wind, melting phlegm, and promoting blood circulation for regulating menstruation	Expectorant, antibechic, and anti-inflammatory	Angelicin, isoferulaldehyde, and 12-hydroxybakuchiol	(Dictionary of Chinese Medicine, 2006; Xu et al., 2015; Zhou et al., 2005)
211	*Sanicula orthacantha* S. Moore	Roots or whole plant	Heat-clearing and detoxifying, treatment of traumatic injury	\	\	(Flora of China, 2002)
212	*Sanicula orthacantha var. Brevispina* H. Boissieu	Whole plant	Heat-clearing and detoxifying, treatment of traumatic injury	\	\	(Flora of China, 2002)
213	***Saposhnikovia divaricata* (Turcz.) Schischk.	Roots	Expelling wind to relieve superficies, removing dampness to relieve pain, and arrest convulsio	Analgesia, sedation, and anti-inflammatory	Prim-*o*-glucosylcimifugin, 5-*O*-methylvisamitol glycoside, and cimifugin	(Chang et al., 2022; Liu et al., 2017b; Pharmacopoeia of the People's Republic of China, 2020)
214	*Selinum cryptotaenium* H. Boissieu	Roots	\	\	\	(Wei et al., 2019)
215	*Semenovia montana* Kamelin & V. M. Vinogr.	Roots	\	\	\	(Zhao et al., 2004)
216	*Seseli delavayi* Franch.	Roots	Expelling wind, removing dampness, and relieving pain	\	\	(Dictionary of Chinese Medicine, 2006)
217	*Seseli mairei var. Mairei*	Roots and rhizome	Expelling wind, removing dampness, and relieving pain	Antipyretic, analgesia, and anti-inflammatory	Sphondin, bergapten and isopimpinellin	(Dictionary of Chinese Medicine, 2006; Gui and Wei, 1991; Gui et al., 1991; Zong et al., 2007)
218	*Seseli yunnanense* Franch.	Roots and rhizome	Expelling wind, removing dampness, and relieving pain	Antipyretic, analgesia, and anti-inflammatory	Falcarindiol, falcarinol, and glycerol monolinoleate	(Dictionary of Chinese Medicine, 2006; Gui and Wei, 1991; Gui et al., 1991; Lin et al., 2017)
219	*Seselopsis tianschanica* Schischk.	Roots	Treatment of fall injury, anemia, and other diseases	Treatment of nasopharynx cancer	\	(Flora of China, 2002)
220	*Sium suave* Walter	Whole plant	Dispersing cold, relieving headache, and decreasing blood pressure	\	\	(Flora of China, 2002; Xu and Chen, 1998)
221	Spuriopimpinella arguta (Diels) X. J. He & Z. X. Wang	Roots and whole plant	\	\	\	(Hu et al., 2012)
222	*Tongoloa silaifolia* (H. Boissieu) H. Wolff	Roots	Stopping bleeding, relieving pain, and activating blood	Treatment of traumatic injury, trauma bleeding, and rheumatic pain	Suberosin, crenulatin, and isoimperatorin	(Dictionary of Chinese Medicine, 2006; Qin et al., 2012; Qin et al., 2013)
223	*Tongoloa stewardii* H. Wolff	Fruits	\	\	\	(Wei et al., 2019)
224	*Torilis japonica* (Houtt.) DC.	Fruits and roots	Lumbricide ascaricide, and external antiphlogistic agent	\	Essential oil	(Dictionary of Chinese Medicine, 2006)
225	*Torilis scabra* (Thunb.) DC.	Ripening fruits or whole plant	Activating blood, insecticide, and antidiarrheal	Bacteriostat	Cyclohexene, 6,6-dimethyl-bicyclo [3.1.1] heptane-2-carboxaldehyde, and endo-borneol	(Dictionary of Chinese Medicine, 2006; Hu et al., 2012; Xu et al., 2022)
226	*Trachyspermum ammi* (L.) Sprague.	Fruits	Dispersing cold, relieving pain, and treatment of indigestion	Antibacterial, antimicrobials, and antifungal	thymol, ρ-cymene, and β-pinene	(Bairwa et al., 2012; Benelli et al., 2017; Dictionary of Chinese Medicine, 2006;

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						Kaur and Arora, 2009; Kaur and Arora, 2010; Shankaracharya et al., 2000)
227	*Vicatia thibetica* H. Boissieu	Roots	Dispelling wind, eliminating dampness, and dispelling cold	Anti-fatigue, antioxidant, and enhancing immunity	Umbelliferone, bergapten, and ferulic acid	(Dong et al., 2018; Zhang et al., 2004; Zhou et al., 2007)
228	*Visnaga daucoides* Gaertn.	Fruits	Treatment of coronary artery disease, such as panhandling coronary thrombosis	Treatment of renal colic, angina pectoris, and urinary calculi	Khellin, visnagin, and khellol glycoside	(Flora of China, 2002; Hong et al., 2022)

2 Note: "*" means the plant reported in Chinese Pharmacopoeia, "**" means the plant roots used as medicine reported in Chinese Pharmacopoeia, the same below.

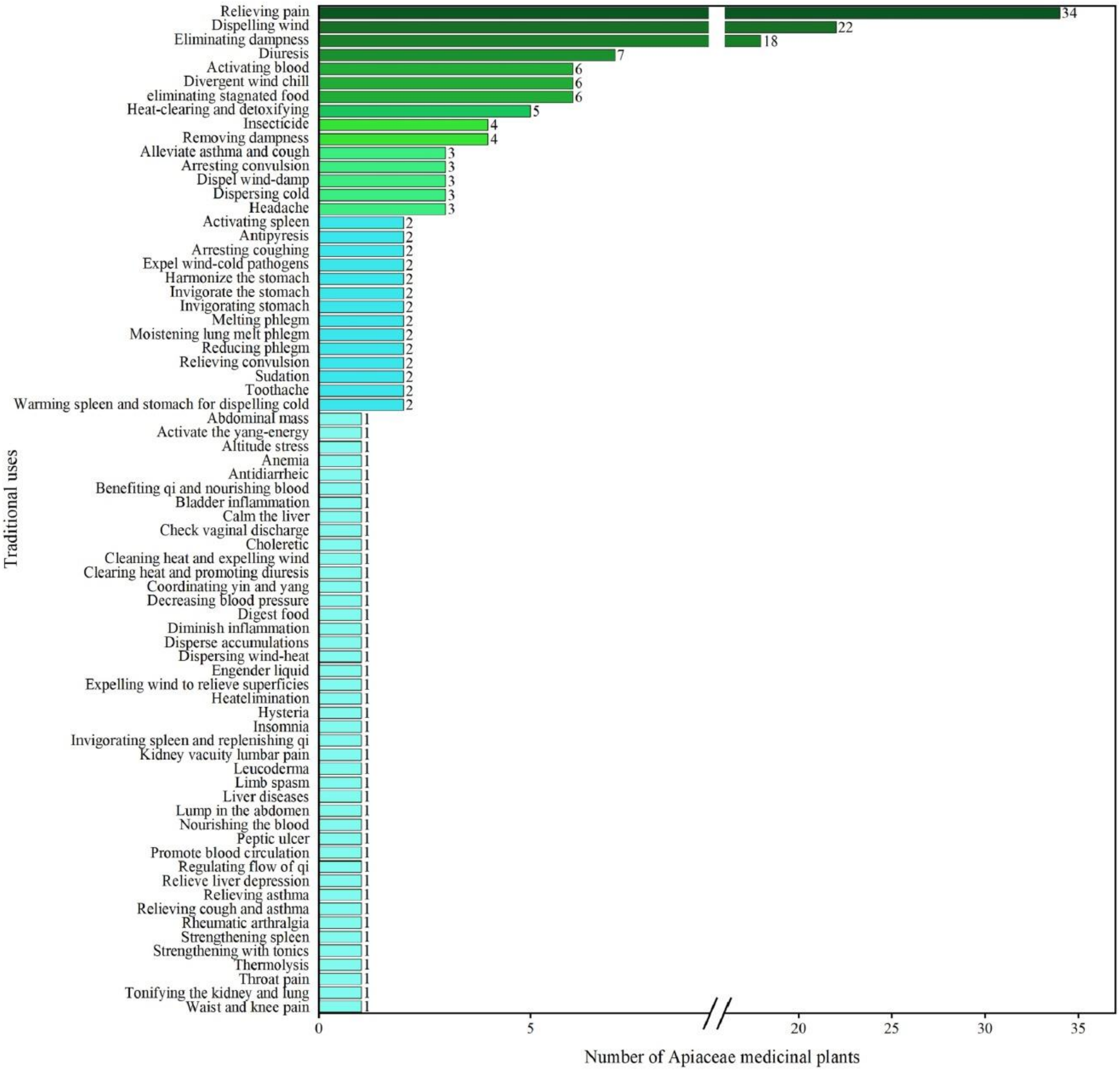

Fig. 2 Traditional use of the 228 AMPs

Meanwhile, AMPs combined with other herbs have also been applied in many prescriptions for thousands of years (Wei et al., 2016b). For example, Decoction of Notopterygium for Rheumatism, a famous Chinese prescription, composed of *Notopterygium incisum*, *Angelica biserrate*, *Ligusticum sinense*, *Eryngium foetidum,* and *Ligusticum chuanxiong*, etc., has been widely used for the treatment of exopathogenic wind-cold, rheumatism, headache, and pantalgia (Wang et al., 2022b). Xinyisan composed of *Yulania liliiflora*, *Actaea cimicifuga*, *Angelica dahurica*, *Eryngium foetidum,* and *Ligusticum sinense*, etc., has been widely used for the treatment of deficiency of pulmonary qi and nasal obstruction due to wind-cold pathogens and damp-heat in lung channel (Wang et al., 2020; Wang et al., 2022b). Shiquan Dabu Wan of *Angelica sinensis*, recorded in *Pharmacopoeia of the People's Republic of China*, has been mainly used for treatment of pallor, fatigability, and palpitations (Shan and Jiao, 2011); and Juanbi Tang of *Notopterygium incisum* and *Angelica biserrate*, recorded in Medical Words (Qing dynasty), has been mainly used for treatment of arthralgia due to wind cold-dampness (Du et al., 2022).

6. Modern pharmacological uses

Modern pharmacological researches of the 228 AMPs were recorded (Table 1). Based on their pharmacological effects, a total of 62 modern uses are enriched (Fig. 3), with 31 species (*e.g.*, *Angelica biserrata*, *Bupleurum. marginatum*, and *Foeniculum vulgare*) have anti-inflammatory activity; 20 species (*e.g.*, *Chuanminshen violaceum*, *Cryptotaenia japonica*, and *Ferula songarica*) have antioxidative activity; 16 species (*e.g.*, *Anethum graveolens*, *Centella asiatica*, and *Changium smyrnioides*) have antitumor activity.

Specifically, the sesquiterpene-coumarin, such as (3'S, 5'S, 8'R, 9'S, 10'R)-kellerin, gummosin, galbanic acid, and methyl galbanate in *Ferula sinkiangensis* resin, showed the anti-neuroinflammatory effect and might be a potential natural therapeutic agent for Alzheimer's disease (Xing et al., 2016). The ferulin B and C in *Ferula ferulaeoides* rhizomes could restrain the multiplication of HepG2 stomach cancer cell lines, and 2,3-dihydro-7-hydroxyl-2R*, 3R*-dimethyl-2-[4,8-dimethyl-3(E),7-nonadienyl]-furo[3,2-c] coumarin could restrain the proliferation of HepG2, MCF-7, and C6 cancer cell lines (Meng et al., 2013; Yang, 2018). The osthole in *Angelica biserrata* could restrain the multiplication of human gastric cancer cell lines MKN-45 and BGC-823, human lung adenocarcinoma cell line A549, human mammary carcinoma cell line MCF-7, and human colon carcinoma cell line LOVO (Lin et al., 2013). The phthalides (*e.g.*, sedanolide and 3-n-butylphthalide) in *Apium graveolens* showed the anticarcinogenic and neuroprotective properties (Kokotkiewicz and Luczkiewicz, 2016; Mišić et al., 2008).

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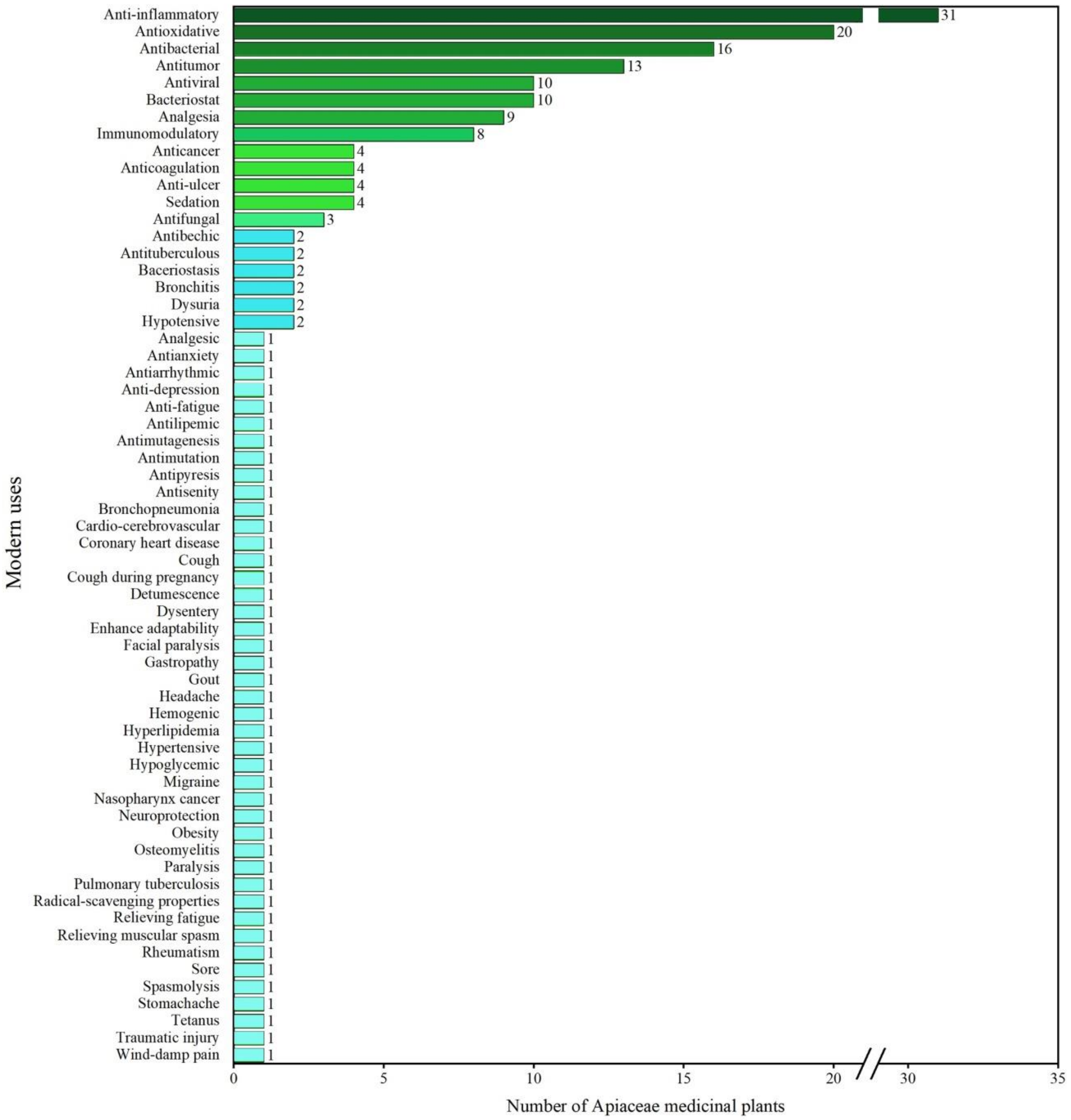

Fig. 3 Modern pharmacological uses of the 228 AMPs

7. Phytochemistry

As shown in Table 1, hundreds of bioactive metabolites have been identified from the 228 AMPs (Wei et al., 2019; Yuan, 1986). Based on their chemical structures, these metabolites can be categorized into 5 main classes including: (1) polysaccharides, (2) alkaloids, (3) phenylpropanoids, (4) flavonoids, and (5) terpenoids (Fig. 4).

Among the 22 AMPs recorded in the *Pharmacopoeia of the People's Republic of China* (2020), 18 bioactive metabolites in the 17 AMPs (*e.g.*, *Angelica biserrata*, *Bupleurum chinense DC.*, and *Centella asiatica*) (Fig. 5) were described as quality control indicators, which include: 11 phenylpropanoids (*i.e.*, osthole, columbianadin, imperatorin, isoimperatorin, nodakenin, ferulic acid, ttrans-anethole, levistilide A, notopterol, praeruptorin A, and praeruptorin B), 4 terpenoids (*i.e.*, saikosaponin a, saikosaponin d, asiaticoside, and madecassoside), 2 chromones (*i.e.*, prim-O-glucosylcimifugin and 5-O-methylvisammioside), and single phthalides (*i.e.*, ligustilide); and there is no specific quality marker mentioned for the other 5 AMPs (*e.g., Changium smyrnioides*, *Daucus carota* L., and *Glehnia littoralis*) (Table 2).

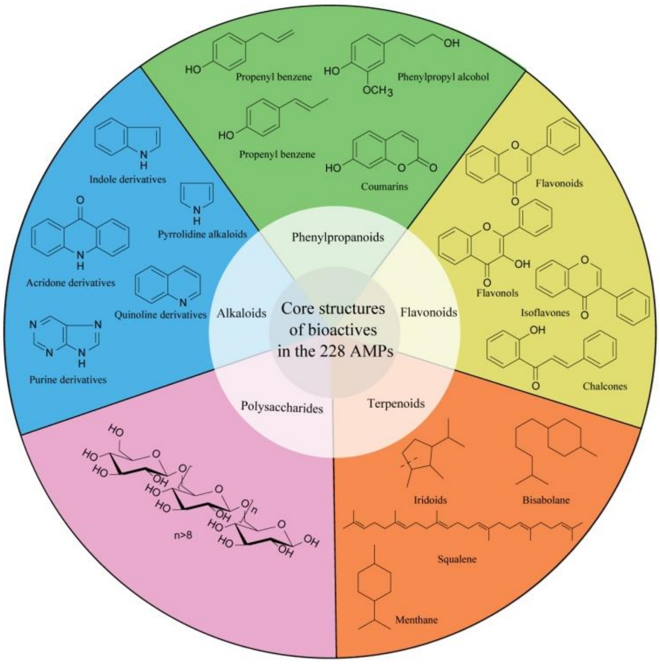

Fig. 4 Core structures of five different kinds of bioactives identified from the 228 AMPs

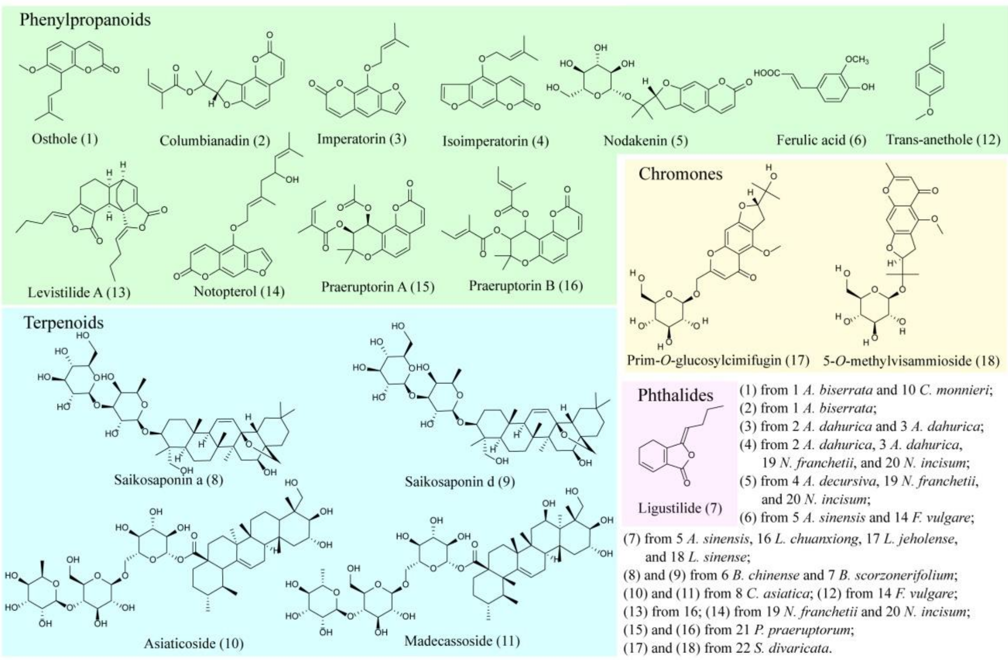

Fig. 5 Structures of 18 quality markers from the 22 AMPs in *Pharmacopoeia of the People's Republic of China*

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Table 2 Quality markers in the 22 AMPs recorded in the *Pharmacopoeia of the People's Republic of China* (2020)

No. /No. in Table 1	Plant species	Quality markers	Classification	Biosynthetic pathway
1/8	*A. biserrata* (R. H. Shan & C. C. Yuan) C. C. Yuan & R. H. Shan	Osthole (1) and columbianadin (2)	Coumarins	Phenylpropanoids
2/10	*A. dahurica* (Fisch. ex Hoffm.) Benth. & Hook. f. ex Franch. & Sav.	Imperatorin (3) and isoimperatorin (4)	Coumarins	Phenylpropanoids
3/11	*A. dahurica cv. Hangbaizhi*	(3) and (4)	Coumarins	Phenylpropanoids
4/13	*A. decursiva* (Miq.) Franch. & Sav.	Nodakenin (5)	Coumarins	Phenylpropanoids
5/20	*A. sinensis* (Oliv.) Diels	Ferulic acid (6) and ligustilide (7)	Propenyl benzenes and Phthalides	Phenylpropanoids and phthalides
6/34	*B. chinense* DC.	Saikosaponin a (8) and saikosaponin d (9)	Triterpenes	Terpenes
7/67	*B. scorzonerifolium* Willd.	(8) and (9)	Triterpenes	Terpenes
8/79	*C. asiatica* (L.) Urb.	Asiaticoside (10) and madecassoside (11)	Triterpenes	Terpenes
9/80	*C. smyrnioides* H. Wolff	–		
10/83	*C. monnieri* (L.) Spreng.	(1)	Coumarins	Phenylpropanoids
11/94	*Daucus carota* L.	–		
12/102	*F. fukanensis* K. M. Shen	–		
13/109	*F. sinkiangensis* K. M. Shen	–		
14/112	*F. vulgare* Mill.	Trans-anethole (12)	Phenylpropene	Phenylpropanoids
15/113	*G. littoralis* F. Schmidt ex Miq.	–		
16/159	*L. chuanxiong* Hort.	(6) and levistilide A (13)	Phenylpropanoids and phthalide	Phenylpropanoids
17/160	*L. jeholense* Nakai et Kitag.	(6)	Phenylpropanoids	Phenylpropanoids
18/162	*L. sinense* Oliv.	(6)	Phenylpropanoids	Phenylpropanoids
19/167	*N. franchetii* H. de Boiss.	(4), (5), and notopterol (14)	Coumarins	Phenylpropanoids
20/168	*N. incisum* Ting ex H. T. Chang	(4), (5), and (14)	Coumarins	Phenylpropanoids
21/186	*P. praeruptorum* Dunn	Praeruptorin A (15) and praeruptorin B (16)	Coumarins	Phenylpropanoids
22/213	*S. divaricata* (Turcz.) Schischk.	Prim-*O*-glucosylcimifugin (17) and 5-*O*-methylvisammioside (18)	Chromones	Chromones

Note: The "–" indicates there are no specific quality markers recorded in the *Pharmacopoeia of the People's Republic of China* (2020).

7.1 Polysaccharides

Polysaccharides are the largest component of biomass and account for *ca.* 90% of the carbohydrates in plants (BeMiller, 2019). Studies have demonstrated that polysaccharides in medicinal plants are the indispensable bioactive compounds presenting uniquely pharmacological effects such as immunomodulatory, hypoglycemic, antitumor, anti-diabetic, and antioxidant, amongst others, with almost no side effect or adverse drug reaction (Li et al., 1999; Zheng et al., 2019). To date, polysaccharides in the 228 AMPs have also been identified to show multiple pharmacological effects. For example, polysaccharides in *A. sinensis* present the effect of hematopoietic, anti-tumor, and liver protection, etc. (Bi et al., 2021; Wei et al., 2016b); polysaccharides in *Angelica dahurica* present the effect of spleen lymphocytes, natural killer cells, and procoagulant, etc (Dong et al., 2021b; Wang et al., 2017); as well as polysaccharides in *Bupleurum chinense* and *Bupleurum smithii* present the effect of macrophage modulation, kidney protection, and inflammatory alleviation, etc. (Liu et al., 2019; Wu et al., 2013; Zhang et al., 2017).

7.2 Alkaloids

About 27 000 alkaloids presenting as water-soluble salts of organic acids, esters, and combined with tannins or sugars have been found in plants (Kukula-Koch and Widelski, 2017). Many alkaloids are valuable medicinal agents that can be utilized to treat various diseases including malaria, diabetes, cancer, cardiac dysfunction, and blood clotting related diseases, etc. (Ain et al., 2016; Marya and Khan, 2016; Perviz et al., 2016). While alkaloids in the 228 AMPs mainly exist in the *Ligusticum*, *Apium*, *Conium*, and *Cuminum* genera (Yuan, 1986). For example, alkaloids in *Ligusticum chuanxiong* show the activity of inhibiting myocardial fibrosis, protecting ischemic myocardium, and relieving cerebral ischemia-reperfusion injury (Pu et al., 2020; Zhang et al., 2020; Zhou et al., 2022); and a novel alkaloid 2-pentylpiperidine named as conmaculatin in *Conium maculatum* shows strong peripheral and central antinociceptive activity (Radulović et al., 2012).

7.3 Phenylpropanoids

Phenylpropanoids are a large class of secondary metabolites biosynthesized from the amino acids, phenylalanine, and tyrosine (Deng and Lu, 2017). Over 8000 aromatic metabolites of the phenylpropanoids that have been identified in plants include simple phenylpropanoids (propenyl benzene, phenylpropionic acid, and phenylpropyl alcohol), coumarins, lignins, lignans, and flavonoids (Böttger et al., 2018).

7.3.1 Simple phenylpropanoids

To date, limited simple phenylpropanoids have been identified from the AMPs, such as 3 phenylpropanoids (*e.g.*, trans-isoelemicin, sarisan, and trans-isomyristicin) in roots of *Ligusticum mutellina* (Spitaler et al., 2002). It is noteworthy that ferulic acid is one of phenylpropionic acids and mainly exists in the *Angelica*, *Ligusticum*, *Ferula*, and *Pleurospermum* genera (Wang et al., 2012; Wei et al., 2016b; Wen and Wang, 2018). Pharmacological studies demonstrate that ferulic acid in *Angelica sinensis* shows strong properties in inhibiting platelet aggregation, increasing coronary blood flow, and stimulating smooth muscle (Lu et al., 2005; Upton, 2003); in *Angelica acutiloba* shows antidiabetic effects, immunostimulant properties, antiinfammatory, antimicrobial, anti-arrhythmic, and antithrombotic activity (Hwang et al., 2022); and in *Ligusticum tenuissimum* shows anti-melanogenic and anti-oxidative effects (Lim et al., 2019).

7.3.2 Coumarins

Coumarins are the most widespread in 20 genera of AMPs (*e.g.*, *Angelica*, *Bupleurum*, and *Peucedanum*) and mainly include simple coumarins, pyranocoumarins, and furocoumarins (Pan et al., 2002; Qiu et al., 2019; Yuan, 1980). In recent years, distinct coumarins have been identified from the AMPs, such as 99 coumarins in *Ferula* (Xing et al., 2012), 116 coumarins in *Angelica decursiva* and *Peucedanum praeruptorum* (Song et al., 2021), as well as 9 coumarins in *Angelica dahurica* (Xie et al., 2022). Furthermore, 8 coumarins have been selected as quality markers including cnidiadin (1) in *Angelica biserrata* and *Cnidium monnieri*, zosimin (2) in *Angelica biserrata*, imperatorin (3) in *Angelica dahurica* and *Angelica dahurica cv. Hangbaizhi*, isoimperatorin (4) in *Angelica dahurica*, *Angelica dahurica cv. Hangbaizhi*, *Notopterygium franchetii*, and *Notopterygium incisum*, nodakenin (5) in *Angelica decursiva*, *Notopterygium franchetii*, and *Notopterygium incisum*, notopterol (14) in *Notopterygium franchetii* and *Notopterygium incisum*, as well as praeruptorin A (15) and praeruptorin B (16) in *Peucedanum praeruptorum* (Table 2 and Fig. 5) (Pharmacopoeia of the People's Republic of China, 2020).

To date, various biological activities of coumarins have been demonstrated including antifungal, antimicrobial, antiviral, anti-cancerous, anti-tumor, anti-inflammatory, anti-filarial, enzyme inhibitors, antiaflatoxigenic, analgesics, antioxidant, and oestrogenic (Fylaktakidou et al., 2004; Ngo et al., 2010; Reddy et al., 2004; Sahni et al., 2021). For example, coumarins are recognized as the main bioactive constituents in *Peucedani* genus and play critical roles in relieving cough and asthma, strengthening heart function, as well as preventing and treating cardiovascular diseases (Wang et al., 2022a).

7.4 Flavonoids

Flavonoids are a group of the most abundant secondary metabolites in plants (Deng and Lu, 2017). Generally, flavonoids can be further categorized into 8 subgroups including: flavones (*e.g.*, apigenin, luteolin, and baicalein), flavonols (*e.g.*, kaempferol, quercetin, and myricetin), flavanones (*e.g.*, naringenin, hesperitin, and liquiritigenin), flavanonols (*e.g.*, dihydrokaempferol, dihydromyricetin, and dihydroquercetin), isoflavones (*e.g.*, daidzein, purerarin, and peterocarpin), aurones, anthocyanidins, and proanthocyanidins (Ballard and Maróstica, 2019; Gebhardt et al., 2005; Kim et al., 2006). In recent years, flavonoids have been identified from the AMPs, such as 6 flavonoids (*e.g.*, luteolin, isoquercitrin, and rutin) in *Ferula* (Yang, 2018), 12 flavonoids (*e.g.*, quercetin-3-*O*-rutinoside, kaempferol-3,7-di-*O*-rhamnoside, quercetin-3-*O*-arabinoside) in Bupleurum (Zhang et al., 2010), and 18 flavonoids (*e.g.*, rutin, quercetin, and quercitrin) in Hydrocotyle (Xiong et al., 2019).

To date, various biological activities of flavonoids have been demonstrated including antioxidant, antiinflammatory, antidiabetic, anticancer, antiobesity, and cardioprotective (Ballard and Maróstica, 2019; Singh et al., 2014). For example, apigenin in *Apium graveolens* shows anticancer property (Zhou et al., 2006), and flavonoids in *Pimpinella diversifolia* DC., *Anthriscus sylvestris*, and *Sanicula astrantiifolia* show antioxidant effect (Dong et al., 2021a; Wang et al., 2014).

7.5 Terpenoids

About 25 000 terpenoids have been reported in plants and they are most diverse secondary metabolites containing three subgroups including: monoterpenoids, sesquiterpenes, and triterpenoids (Yonekura-Sakakibara and Saito, 2009). Actually, terpenoids have been also identified from the AMPs, such as 4 terpenoids (*e.g.*, angelicoidenol, pregnenolone, and β-sitosterol) in *Pleurospermum* (Li et al., 2002), 75 terpenoids (*e.g.*, myrcene, farnesene, and xiongterpene) in *Ligusticum* (Zhao, 2006), 109 terpenoids (*e.g.*, nerolidol, guaiol, and ferulactone A) in *Ferula* (Xing et al., 2012), and 13 triterpenoids (*e.g.*, ranuncoside, oleanane, and barrigenol) in *Hydrocotyle sibthorpioides* Lam. (Xu et al., 2013).

Studies have found that terpenoids possess various biological activities such as anti-inflammatory, anti-oxidation, and anti-fibrosis activities, anti-tumor, anti-Alzheimer's disease, and anti-depression (Qin et al., 2021; Yuan et al., 2022). For example, xiongterpene in *Ligusticum chuanxiong* shows insecticide effect (Zhang et al., 2020), asiaticoside in *Centella asiatica* shows anti-tumor property (Zhou et al., 2020), as well as saikosaponin d in *Bupleurum chinense* DC. and *Bupleurum scorzonerifolium* Willd. shows the effect of reducing blood glucose, inhibiting inflammation, and reducing insulin resistance (Song et al., 2022).

7.6 Other compounds

Phthalides and chromones also exist in the AMPs and show pharmacological properties. Specifically, phthalides (*e.g.*, ligustilide, *n*-butylidenephthalide, and *Z*-ligustilide) in the *Angelica sinensis* show the effect of inhibiting vasodilation, decreasing platelet aggregation, as well as exerting analgesic, anti-inflammatory, and anti-proliferative (Wei et al., 2016b); butylphthalide in *Ligusticum sinense* shows the effect of anti-inflammatory, antithrombus, dilate blood vessels, improve brain microcirculation, and anti-myocardial ischemia (Tang, 2011).

For the chromones, 3 chromones [*i.e.*, 5 thydroxy 2 [(angebyloxy) mehyI] fuan [3, 2': 6, 7] chrmone, angeliticin A, and noreugenin)] in *Angelica polymorpha* (Li et al., 2009b), 10 chromones (*e.g.*, cnidimoside A, cnidimol B, and peucenin) in *Cnidiummonnieri* (L.) Cuss. (Tian et al., 2020), and 22 chromones [*e.g.*, edebouriellol, hamaudol, and 3′(R)-(+)-hamaudol] in *Saposhnikovia divaricata* (Chang et al., 2022) have been identified. Studies have found that 2 chromones 3′S-(-)-*O*-acetylhamaudol and (±)-hamaudol in *Angelica morii* show the effect of inhibiting Ca^{2+} influx of vascular smooth muscle (Sun et al., 2003a), prim-*O*-glucosylcimifugin and 5-*O*-methylvisammioside show the effect of antipyretic, analgesic, and anti-inflammatory (Xue et al., 2000), and chromones in *Bupleurum multinerve* shows the analgesic effect (Shan et al., 2004).

8. Effect of bolting and flowering (BF) on yield and quality

Previous literatures have repeatedly emphasized that the BF reduces the yield and quality of plants, especially in rhizomatous medicinal plants (Zhao et al., 2016). Here, a total of 38 rhizomatous plants reported in the 228 AMPs are associated with the BF (Table 3). Based on the influence level of the BF on the yield and quality, the 38 rhizomatous AMPs belonging to 17 genera can be categorized into 3 classes including: (1) the BF significantly affects the yield and quality of 14 AMPs (*i.e.*, *Angelica acutiloba*, *Angelica biserrata*, *Angelica dahurica*, *Angelica dahurica cv. Hangbaizhi*, *Angelica decursiva*, *Angelica polymorpha*, *Angelica sinensis*, *Daucus carota*, *Heracleum hemsleyanum* Diels, *Heracleum rapula*, *Libanotis iliensis*, *Libanotis seseloides*, *Peucedanum praeruptorum*, and *Saposhnikovia divaricata*), and their rhizomes and/or roots are wholly lignified and absolutely useless for clinical effects; (2) the BF differently affects the yield of 11 AMPs (*i.e.*, *Angelica gigas*, *Bupleurum chinense*, *Bupleurum scorzonerifolium* Willd., *Changium smyrnioides*, *Chuanminshen violaceum*, *Glehnia littoralis*, *Ligusticum chuanxiong*, *Ligusticum jeholense* Nakai et Kitag., *Ligusticum sinense* Oliv., *Notopterygium franchetii*, and *Notopterygium incisum*), while their rhizomes or roots can be used as medicine to some extent; as well as (3) the BF has no significant effect on the yield and quality of 13 AMPs (*i.e.*, *Angelica sylvestris*, *Cicuta virosa*, *Ferula ferulaeoides*, *Ferula fukanensis*, *Ferula lehmannii*, *Ferula olivacea*, *Ferula sinkiangensis*, *Ferula teterrima*, *Levisticum officinale*, *Libanotis buchtormensis*, *Libanotis lancifolia*, *Libanotis spodotrichoma*, and *Pimpinella candolleana*), and their rhizomes or roots are used as medicine without doubted (Fig. 6).

For the class (1), representatively, a 8.3- and 16.1-fold reduction of dry weight and quality marker ferulic acid content in *Angelica sinensis* (Li et al., 2020b); and a 1.5- and 1.5-fold reduction of dry weight and quality marker isoimperatorin content in *Angelica dahurica* (Zhang et al., 2005b) have been observed after the BF. For the class (2), a 1.34-fold reduction of saikosaponinsands, while no significant change of dry weight in *Bupleurum chinense* (Yu et al., 2003; Zhao et al., 2017); and a 2.0- and 1.7-fold reduction of dry weigh and polysaccharides content in *Changium smyrnioides* (Guo et al., 2007) have been observed after the BF. For the class (3), the yield and quality of the 13 AMPs are not affected by the harvest stages (Dictionary of Chinese Medicine, 2006).

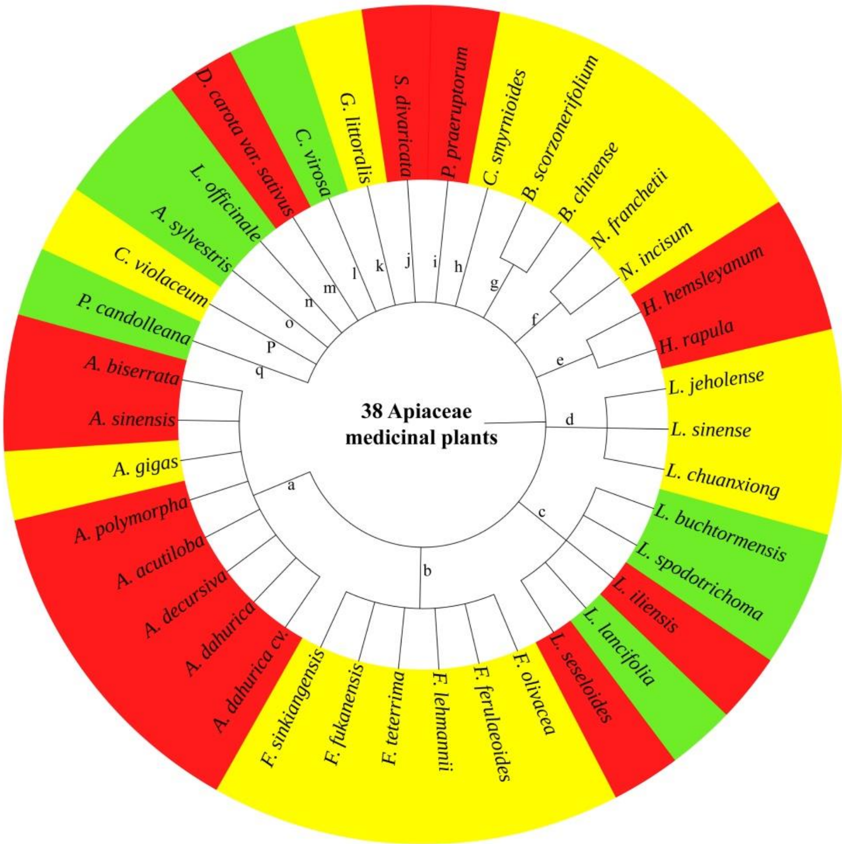

Fig. 6 Cluster of the 38 rhizomatous AMPs affected by the bolting and flowering. The red color shows that the BF significantly affects the yield and quality; the yellow color shows that the BF differently affects the yield while the rhizomes or roots can be used as medicine to some extent; and the green color shows that the BF has no significant effect on the yield and quality. Different lower case letters a: *Angelica*, b: *Ferula*, c: *Libanotis*, d: *Ligusticum*, e: *Heracleum*, f: *Notopterygium*, g: *Bupleurum*, h: *Changium*, i: *Peucedanum*, j: *Saposhnikovia*, k: *Glehnia*, l: *Cicuta*, m: *Daucus*, n: *Levisticum*, o: *Anthriscus*, p: *Chuanminshen*, and q: *Pimpinella*.

9. Approach to control the BF

The flowering of plants is affected by internal factors (*e.g.,* germplasm resource, seedling age, and seedling size) and external factors (*e.g.,* vernalization, photoperiodism, and environmental stresses) (Lincoln and Eduardo, 2010). Generally, Apiaceae plants are "low-temperature and long-day" perennial herbs, in other words, the plants must experience vernalization (*i.e.,* an extended period of cool weather at 0 to 10℃) and long days (> 12 h daylight) to induce the BF, such as *Angelica sinensis* (Liu et al., 2022), *Daucus carota* (Yan and Hunt, 1999), and *Coriandrum sativum* (Liu et al., 2017a).

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Table 3 Classification of the 38 rhizomatousAMPs affected by the BF

No. /No. in Table 1	Plant species	Classes	References	No. /No. in Table 1	Plant species	Classes	References
1/4	*Angelica acutiloba* (Siebold & Zucc.) Kitag.	(1)	(Wang, 2021)	20/109	**Ferula sinkiangensis* K. M. Shen	(3)	(Dictionary of Chinese Medicine, 2006)
2/8	***Angelica biserrata* (R. H. Shan & C. C. Yuan) C. C. Yuan & R. H. Shan	(1)	(Yan et al., 2012)	21/111	*Ferula teterrima* Kar. & Kir.	(3)	(Dictionary of Chinese Medicine, 2006)
3/10	***Angelica dahurica* (Fisch. ex Hoffm.) Benth. & Hook. f. ex Franch. & Sav.	(1)	(Wei et al., 2007)	22/113	***Glehnia littoralis* F. Schmidt ex Miq.	(2)	(Zhou and Li, 2008)
4/11	***Angelica dahurica cv. Hangbaizhi*	(1)	(Wei et al., 2007)	23/121	*Heracleum hemsleyanum* Diels	(1)	(Yan et al., 2012)
5/13	***Angelica decursiva* (Miq.) Franch. & Sav.	(1)	(Zhou, 1989)	24/126	*Heracleum rapula* Franch.	(1)	(Dictionary of Chinese Medicine, 2006)
6/14	*Angelica gigas* Nakai	(1)	(Lee et al., 2019)	25/148	*Levisticum officinale* W. D. J. Koch	(3)	(Dictionary of Chinese Medicine, 2006)
7/19	*Angelica polymorpha* Maxim.	(1)	(Dictionary of Chinese Medicine, 2006)	26/149	*Libanotis buchtormensis* (Fisch.) DC	(3)	(Xue, 2011)
8/20	***Angelica sinensis* (Oliv.) Diels	(1)	(Li et al., 2020a)	27/150	*Libanotis iliensis* (Lipsky) Korovin	(1)	(Dictionary of Chinese Medicine, 2006)
9/26	*Anthriscus sylvestris* (L.) Hoffm.	(3)	(Wang, 2018a)	28/151	*Libanotis lancifolia* K. T. Fu	(3)	(Dictionary of Chinese Medicine, 2006; Xue, 2011)
10/34	***Bupleurum chinense* DC.	(2)	(Chen et al., 2021)	29/153	*Libanotis seseloides* (Fisch. & C. A. Mey. ex Turcz.) Turcz.	(1)	(Dictionary of Chinese Medicine, 2006)
11/67	***Bupleurum scorzonerifolium* Willd.	(2)	(Chen et al., 2021)	30/155	*Libanotis spodotrichoma* K. T. Fu	(3)	(Dictionary of Chinese Medicine, 2006; Xue, 2011)
12/80	***Changium smyrnioides* H. Wolff	(2)	(Wang et al., 2010)	31/159	***Ligusticum chuanxiong* Hort.	(2)	(Jiang et al., 2008)
13/81	*Chuanminshen violaceum* M. L. Sheh & R. H. Shan	(2)	(Sun et al., 2017)	32/160	***Ligusticum jeholense* Nakai et Kitag.	(2)	(Zhao et al., 2013)
14/82	*Cicuta virosa* L.	(3)	(Dictionary of Chinese Medicine, 2006)	33/162	***Ligusticum sinense* Oliv.	(2)	(Zhao et al., 2013)
15/96	*Daucus carota var. sativus* Hoffm.	(1)	(Ou et al., 2016)	34/167	***Notopterygium franchetii* H. de Boiss.	(2)	(Huang and Ceng, 2018)
16/102	*Ferula feruloides* (Steud.) Korovin	(3)	(Dictionary of Chinese Medicine, 2006)	35/168	***Notopterygium incisum* Ting ex H. T. Chang	(2)	(Huang and Ceng, 2018)
17/103	*Ferula fukanensis* K. M. Shen	(3)	(Dictionary of Chinese Medicine, 2006)	36/186	***Peucedanum praeruptorum* Dunn	(1)	(Wang et al., 2007)
18/106	*Ferula lehmannii* Boiss.	(3)	(Dictionary of Chinese Medicine, 2006)	37/195	*Pimpinella candolleana* Wight & Arn.	(3)	(Dictionary of Chinese Medicine, 2006)
19/108	*Ferula olivacea* (Diels) H. Wolff ex Hand.-Mazz.	(3)	(Dictionary of Chinese Medicine, 2006)	38/213	***Saposhnikovia divaricata* (Turcz.) Schischk.	(1)	(Li, 1995)

Note: (1) the BF significantly affects the yield and quality, and the rhizomes or roots are absolutely useless for clinical effects; (2) the BF differently affects the yield, while the rhizomes or roots can be used as medicine to some extent; and (3) the BF has no significant effect on the yield and quality, and their rhizomes or roots are used as medicine without doubtedly, the same below.

To inhibit the occurrence of BF of AMPs, plenty of measures that have been used include: breeding new cultivars to reduce the BF (Huang and Jin, 2018), controlling the seedling age and size to delay the transition from vegetative growth to flowering (Qiu et al., 2010), storing seedlings at freezing temperatures to avoid vernalization (Liu et al., 2022), growing the plants under sunshade to avoid long-day photoperiodism (Yao, 2005), and planting with standard techniques to reduce pests and diseases (Li et al., 2005) (Fig. 7).

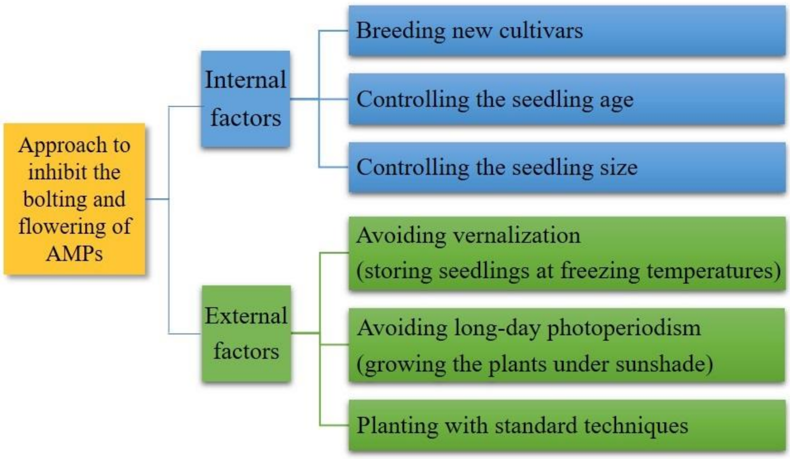

Fig. 7 Approach to control the BF of AMPs

As shown in Table 4, approaches to inhibit the BF of 24 AMPs have been listed. For example, the bolting rate of *Angelica sinensis* can be significantly decreased through planting the green stem cultivar (Mingui 2) instead of the purple stem cultivar (Mingui 1) (Huang and Jin, 2018), selecting smaller seedlings (*i.e.*, root-shoulder diameter <0.55 cm) instead of larger seedlings (Qiu et al., 2010; Wang, 1977), storing the seedlings at freezing temperature (*i.e.*, <0℃) during overwinter stage (Liu et al., 2022), shading the plants under sunshade (*i.e.*, >40%) during growth stage (Yao, 2005), and providing the plants with good growth conditions (*e.g.*, plant intensity, nutrient and water balance) (Li et al., 2005). The bolting rate of *Angelica dahurica* can be significantly decreased through planting the purebreeds (Yang et al., 2001), selecting the immature seeds for seeding (Wei et al., 2007), increasing the potassic fertilizer while decreasing the nitrogen and phosphorus fertilizers (Pu et al., 2011), and planting with standard techniques (Yi et al., 2011). The bolting rate of *Saposhnikovia divaricata* can also be significantly decreased through controlling the sunshade (Meng et al., 2004), sowing date (Wang et al., 2013), planting density (Tong et al., 2010), and preventing the excessive growth (Meng et al., 2004).

Table 4 Approach to inhibit BF of 24 AMPs have been reported

Classes	No. /No. in Table 1	Plant species	Measure I (Seeding)	Measure II (Cultivation)	Measure III (Abiotic)	Measure IV (Molecular biology)
(1)	1/4	*Angelica acutiloba* (Siebold & Zucc.) Kitag.	Seedling diameter (Zhang et al., 2016)	Density of planted seedlings (Zhang et al., 2016)	Paclobutrazol concentration (Zhang et al., 2016)	\
(1)	2/8	***Angelica biserrate* (R. H. Shan & C. C. Yuan) C. C. Yuan & R. H. Shan	Seedling size and root length (Yan et al., 2012)	\	\	\
(1)	3/10	***Angelica dahurica* (Fisch. ex Hoffm.) Benth. & Hook. f. ex Franch. & Sav.	Seed quality (Yang et al., 2001) Seed maturity degree (Wei et al., 2007)	Soil selection should avoid continuous cropping and fertile sticky soil (Yang et al., 2001) Density of planted seedlings (Yi et al., 2011) Seeding time (Chen et al., 1999; Yang et al., 2001)	Rational application of fertilizer (Yang et al., 2001) Appropriate N, P, and K fertilizer (Ding et al., 1999; Wei et al., 2007)	Seven types of reproductive conversion genes (He, 2018) *Adconstans-like* gene (*adcol4*, *adcol5b*, *adcol10a*, *adcol13a* and *adcol16a*) (Jiang et al., 2021)
(1)	4/11	***Angelica dahurica* cv. Hangbaizhi	Seed quality (Yang et al., 2001) Seed maturity degree (Wei et al., 2007)	Soil selection should avoid continuous cropping and fertile sticky soil (Yang et al., 2001) Density of planted seedlings (Yi et al., 2011) Seeding time (Chen et al., 1999; Yang et al., 2001)	Rational application of fertilizer (Yang et al., 2001) Appropriate N, P, and K fertilizer (Ding et al., 1999; Wei et al., 2007)	Seven types of reproductive conversion gene (He, 2018) *Adconstans-like* gene (*adcol4*, *adcol5b*, *adcol10a*, *adcol13a* and *adcol16a*) (Jiang et al., 2021)
(1)	5/13	***Angelica decursiva* (Miq.) Franch. & Sav.	\	\	\	\
(1)	6/19	*Angelica polymorpha* Maxim.	\	\	\	\
(1)	7/20	***Angelica sinensis* (Oliv.) Diels	Seed maturity degree (Wang and Zhang, 1982), seeding age (Wang, 1977), seeding weight (Li, 1983), root diameter (Lin et al., 2007) and excellent variety (Huang and Jin, 2018)	Short light (Wang and Zhang, 1982), storage temperature (Wang, 1979), and reasonable planting and cultivation (Li et al., 2020a)	Plant growth retardant (Zhang, 1999)	Four pathways of genes for regulating early bolting and flowering (Li et al., 2021a; Li et al., 2021c)
(1)	8/121	*Heracleum hemsleyanum* Diels	\	\	\	\
(1)	9/126	*Heracleum rapula* Franch.	\	\	\	\
(1)	10/150	*Libanotis iliensis* (Lipsky) Korovin	\	\	\	\
(1)	11/153	*Libanotis seseloides* (Fisch. & C. A. Mey. ex Turcz.) Turcz.	\	\	\	\
(1)	12/186	***Peucedanum praeruptorum* Dunn	\	Compact planting (Xu et al., 2021), seeding time (Jian et al., 2020; Xu et al., 2021)	\	\
(1)	13/213	***Saposhnikovia divaricata* (Turcz.) Schischk.	\	Density of planted seedlings (Tong et al., 2010)	\	Transcriptomic analysis identifies differentially expressed genes associated with bolting and flowering during early flowering, flower bud differentiation and late flowering (Liu

						et al., 2018)
(2)	14/14	*Angelica gigas* Nakai	\	\	\	\
(2)	15/34	***Bupleurum chinense* DC.	\	Cut the flowers (Chen et al., 2021)	Temperature (Sun, 1981)	Flowering gene (*bcsvp*, *bcpaf1*, *bcco and bcft*) (Li et al., 2021b)
(2)	16/67	***Bupleurum scorzonerifolium* Willd.	\	\	\	\
(2)	17/80	*Changium smyrnioides* H. Wolff	\	Cut the flowers (Wang et al., 2010)	\	\
(2)	18/81	*Chuanminshen violaceum* M. L. Sheh & R. H. Shan	\	\	\	\
(2)	19/113	***Glehnia littoralis* F. Schmidt ex Miq.	\	Cut the flowers (Zhou and Li, 2008)	\	\
(2)	20/159	***Ligusticum chuanxiong* Hort.	Asexual reproduction (Jiang et al., 2008) Tissue cultur (Chen et al., 2018)	Cut the bolted stem (Zhao, 2020)	\	Transcriptome original data by Illumina sequencing technology (Song, 2015)
(2)	21/160	***Ligusticum jeholense* Nakai et Kitag.	\	Cut the flower (Feng et al., 2016; Zhao et al., 2007b)	\	\
(2)	22/162	***Ligusticum sinense* Oliv.	\	Cut the flower (Feng et al., 2016; Zhao et al., 2007b)	\	\
(2)	23/167	***Notopterygium franchetii* H. de Boiss.	\	Cut the flower (Yin and Jin, 2009)	\	\
(2)	24/168	***Notopterygium incisum* Ting ex H. T. Chang	\	Cut the flower (Huang and Ceng, 2018)	\	\

10. The mechanism of BF inducing the rhizome lignification

Extensive experiments have demonstrated that the BF induces the lignification of fleshy rhizomes, meanwhile, enhances the degradation of bioactive metabolites (Huang and Jin, 2018; Li et al., 2022b; Zhao et al., 2016). Studies on anatomical structures reveal that the ratio of secondary phloem to secondary xylem respectively changes from 2:1 to 1:10 and 2/5-1/2 to 1/2-3/4 for the rhizomes of *Angelica sinensis* and *Angelica dahurica* before and after BF, meanwhile, the number of secretory cells producing essential oils significantly decreased (Jing and Hu, 1981; Ma et al., 2005b).

As known, lignin biosynthesis belongs to the general phenylpropanoid pathway, which starts from phenylalanine and is catalyzed by a serial of enzymes (Bohnert et al., 2008; Li et al., 2022b). Specifically, phenylalanine is catalyzed to form *p*-Coumaroyl CoA sequentially through the 3 enzymes phenylalanine ammonia lyase (PAL), cinnamate 4-hydroxylase (C4H), and 4-coumarate-CoA ligase (4CL); lignin biosynthesis is synthesized via 3 sub-pathways including: (1) lignins are catalyzed to from *p*-Coumaroyl CoA sequentially through the three enzymes cinnamoyl-CoA reductases (CCR), cinnamyl alcohol dehydrogenases (CAD), and laccases (LACs); and then coniferyl aldehyde is catalyzed to from *p*-Coumaroyl CoA sequentially through the 4 enzymes hydroxycinnamoyl shikimate/quinate transferase (HCT), *p*-coumarate 3-hydroxylase (C3H), caffeoyl-CoA 3-*O*-methyltransferase (CCOMT), and cinnamoyl-CoA reductases (CCR); (2) lignins are catalyzed to from coniferyl aldehyde sequentially through the 2 enzymes CAD and LACs; as well as (3) lignins are catalyzed to from coniferyl aldehyde sequentially through the 3 enzymes ferulate 5-hydroxylase (F5H), caffeic acid 3-*O*-methyltransferase (COMT), and LACs (Fig. 8).

Although lignin biosynthesis has been depicted, studies on the mechanism of BF inducing rhizome lignification are still limited. To our knowledge, only the mechanism of BF affecting *Angelica sinensis* has been conducted, with the expression level of genes (*e.g.*, *PAL1*, *4CLs*, *HCT*, *CAD1*, and *LACs*) significantly upregulated at the stem-node forming and elongating stage compared with stem-node pre-differentiation stage, leading to the reduction of accumulation of bioactive metabolites (*i.e.*, ferulic acid and flavonoids) (Li et al., 2022b).

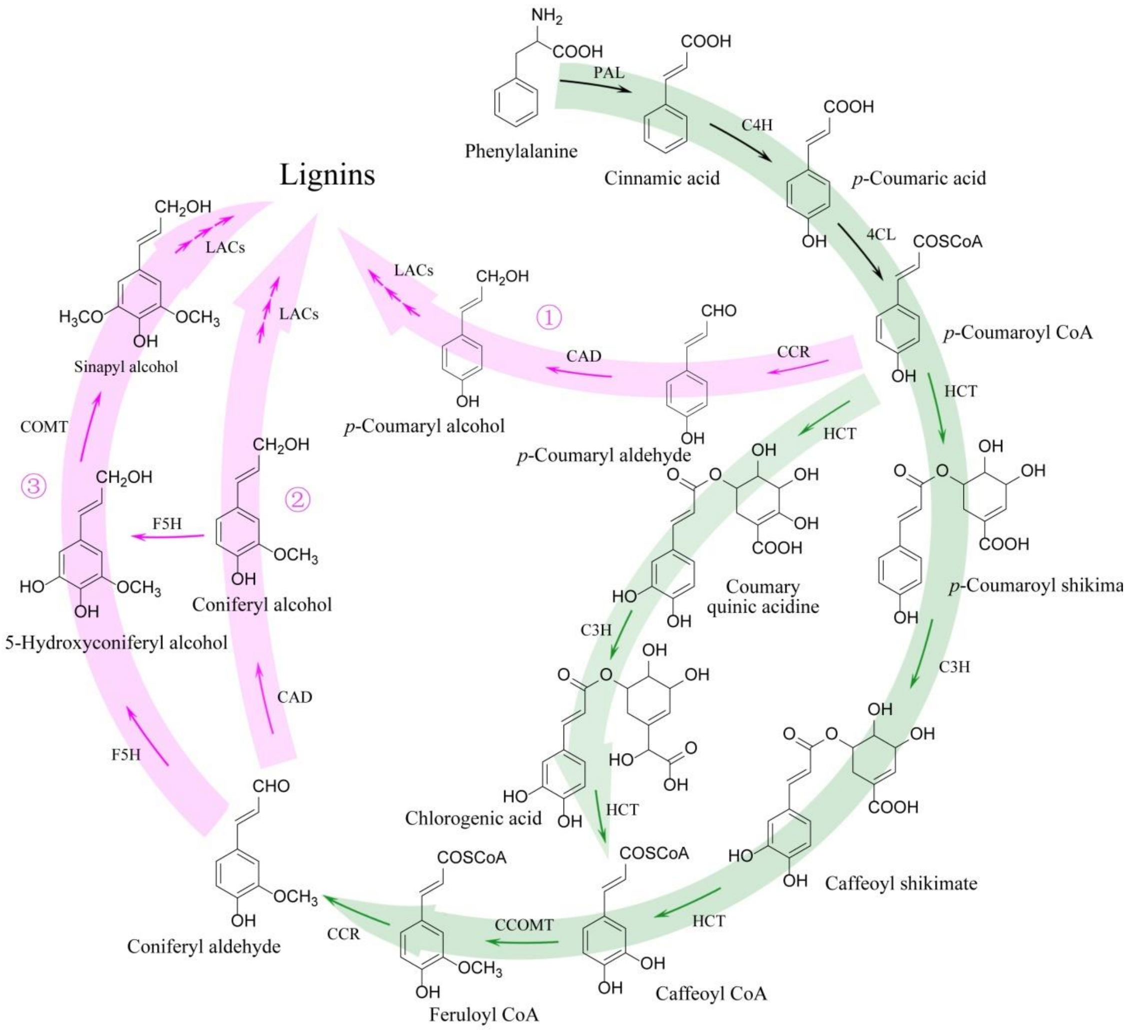

Fig. 8 Schematic representation of biosynthetic pathways of lignins. Abbreviations: PAL, phenylalanine ammonia lyase; C4H, cinnamate 4-hydroxylase; C3H, p-coumarate 3-hydroxylase; COMT, caffeic acid 3-O-methyltransferase; 4CL, 4-coumarate-CoA ligase; HCT, hydroxycinnamoyl shikimate/quinate transferase; CCOMT, caffeoyl-CoA 3-O-methyltransferase; CCR, cinnamoyl-CoA reductases; CHS, chalcone synthase; CHI, chalcone isomerase; CAD, cinnamyl alcohol dehydrogenases; F5H, ferulate 5-hydroxylase; LACs, laccases. The green color shows the common phenylpropanoid pathway of phenylpropanoids, and the red color shows the lignin biosynthetic sub-pathway.

11. Conclusions

In this review, we summarized the tour of AMPs, classification of AMPs species, traditional use, modern pharmacological research, phytochemistry, effect of BF on yield and quality, approach to control the BF, and the mechanism of BF inducing the rhizome lignification.

Apiaceae plants are widely used as TCMs with a variety of pharmacological properties, which largely depend on bioactive metabolites such as polysaccharides, alkaloids, volatile oils, etc.

With the development of Chinese civilization, a total of 228 AMPs have been used as TCMs with 93 species recorded in *Flora of China*, 96 species in *Collection of National Chinese Herbal Medicine*, and 22 species in *Pharmacopoeia of the People's Republic of China*. Based on the medicinal parts, the AMPs are categorized into 6 classes including: the whole plants, rhizomes and/or roots, stems, leaves, fruits, and seeds. Based on the clinical agents, 72 traditional uses are enriched such as relieving pain, dispelling wind, and eliminating dampness. Based on the pharmacological effects, 62 modern uses are enriched such as anti-inflammatory, antioxidative, and antitumor activities. Based on the chemical structures, their metabolites are categorized into 5 main classes including: polysaccharides, alkaloids, phenylpropanoids, flavonoids, and terpenoids.

While several urgent problems in practical production, especially in the BF significantly reducing the yield and quality of the rhizomatous medicinal plants, have not been solved so far. Based on the influence levels, 38 rhizomatous AMPs are categorized into 3 classes including: (1) the BF significantly affects the yield and quality, and the rhizomes and/or roots are wholly lignified and absolutely useless for clinical effects; (2) the BF differently affects the yield, while their rhizomes or roots can be used as medicine to some extent; (3) the BF has no significant effect on the yield and quality, and their rhizomes or roots are used as medicine without doubted. To date, the occurrence of BF regulated by internal factors (*e.g.*, germplasm resource, seedling size, and plant age) and external factors (*e.g.*, vernalization, photoperiodism, and environmental stresses) have been demonstrated, and the mechanism of BF inducing the rhizome lignification has been revealed to some extent.

Presently, several attempts have been made to control the BF of *Angelica sinensis*, *Angelica dahurica*, and *Saposhnikovia divaricata*. Representatively, the BF rate of *Angelica sinensis* can be significantly inhibited by selecting good cultivars, controlling the seedling size, storing the seedlings at freezing temperature to avoid the vernalization, shading the plants under sunshade to avoid the long-day photoperiodic, and providing the plants with good growth conditions. However, these measures have not been widely applied in the practical production, largely relying on the lack of extensive demonstration and promotion.

In order to effectively control the BF of the rhizomatous AMPs, two main measures should be conducted including: planting with standard techniques to provide good nutrients and reduce the stress conditions, as well as innovating new cultivars using the CRISPR/Cas9 system to edit key genes involved in flowering. We believe that this review will provide new insights into the exploration and utilization, improvement of yield and quality, and inhibition of BF of AMPs.

Author contributions

Meiling Li collected and analyzed the references, drew the chemical structures, and wrote the manuscript; Min Li checked the classification and traditional use of Apiaceae medicinal plants; Li Wang checked the language and modern pharmacological use; Mengfei Li and Jianhe Wei supervised the work and revised the manuscript.

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