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Review

Ethnopharmacology, phytochemistry, pharmacology and product application of *Platycodon grandiflorum*: A review

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ABSTRACT

Platycodonis Radix (Jiegeng in Chinese) is a well-known traditional Chinese medicine used for both medicinal and culinary purposes. Its historical use as an antitussive and expectorant has been extensively documented. Researchers, to date, have identified 219 chemical constituents in *Platycodon grandiflorum* (Jacq.) A. DC, encompassing 89 saponins, 11 flavonoids, 21 polysaccharides, 14 phenolic acids, six polyacetylenes, five sterols, 34 fatty acids, 17 amino acids, and 22 trace elements. Jiegeng exhibits diverse pharmacological effects, including antitussive and anti-phlegm properties, anti-cancer activity, anti-inflammatory effects, immune regulation, antioxidant properties, anti-obesity, and antidiabetic effects. Additionally, Jiegeng shows potential in protecting the heart and liver. Beyond its medicinal benefits, Jiegeng is highly esteemed in culinary applications, and its global demand is on the rise. Its utilization has expanded beyond medicine and food to encompass daily necessities, cosmetics, agricultural supplies, and other fields. Currently, there are 18 272 patents related to *P. grandiflorum*. This comprehensive review summarizes the latest research published over the past 20 years, providing a robust foundation for further exploration of the medicinal and health benefits of *P. grandiflorum*.

Contents

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1. Introduction

Platycodon grandiflorum (Jacq.) A. DC is a perennial herbaceous flowering plant belonging to the *Platycodon* genus in the Campanulaceae family (Fig. 1). This plant has been utilized for medicinal and culinary purposes for thousands of years (Sun et al., 2018; Zhang, Xie, et al., 2023). *P. grandiflorum* is predominantly distributed in Asian countries in the Northern Hemisphere, including China, Japan, North Korea, and Eastern Siberia. It is also found in specific regions of Africa in the southern hemisphere. The variant of *P. grandiflorum* originating from eastern China is known as "Nan Jiegeng" and is esteemed for its superior qualities. In contrast, *P. grandiflorum* sourced from North China and Northeast China, referred to as "Bei Jiegeng", is characterized by higher production levels (Jiang, Zu, & Li, 2018; Lu et al., 2018). *Platycodonis Radix* (Jiegeng in Chinese) possess a slightly sweet or bitter taste and other mild properties (Chinese Pharmacopoeia Commission, 2020). As a traditional Chinese medicine (TCM), Jiegeng were first documented in the *Shennong's Classic of Materia Medica* (Shennong Bencao Jing in Chinese) during the Eastern Han Dynasty (25–220 CE). Its efficacy was described as alleviating symptoms such as chest and hypochondriac pain, abdominal fullness, faint bowel sounds, palpitations, and shortness of breath. In ancient times, it was employed to aid in lung ventilation and promote pharyngeal health. Recognized as a drug transporter, Jiegeng was used to deliver medications to the affected upper body areas, making it effective in treating upper body diseases (Chang, Sun, Zheng, Kang, & Zhang, 2023). Modern pharmacological studies have revealed that the main active ingredients in Jiegeng are triterpene saponins, flavonoids, and polysaccharides, exhibiting diverse biological activities such as anti-tumor, anti-tussive, expectorant, anti-inflammatory, anti-bacterial, and anti-oxidant properties (Lee, Yoon, Kim, & Lim, 2004). Jiegeng also contains fatty acids, amino acids, vitamins, and other beneficial nutrients (Wang et al., 2022a). Beyond its medicinal applications, Jiegeng is widely incorporated as an edible ingredient in pickles, assorted dishes, sausages, preserved fruits, and health beverages in China, Japan, and Korea.

This comprehensive review summarizes information on the traditional uses, ethnopharmacology, chemical composition, pharmacological efficacy, homology of medicine and food, and the research and development of *P. grandiflorum* products over the past 20 years. It serves as a reliable foundation for further development and utilization of *P. grandiflorum* as a homologous product in both medicine and food.

2. Traditional uses and ethnopharmacology

P. grandiflorum is utilized for both medicinal and culinary purposes in various countries, including Japan, South Korea, and China. As a perennial plant, Jiegeng has application in both food and medicine, with a typical growth cycle spanning 2–3 years. Researchers established fingerprints for 25 Jiegeng batches across four different age groups, analyzing the platycodon saponin D (PD) content in each batch. The results revealed that the average PD content in annual Jiegeng was 0.035%, while it was 0.042% in biennial Jiegeng. These values fell short of the standards outlined in the 2020 edition of the *Chinese Pharmacopoeia*, which specifies a minimum PD content of 0.10%. However, the average PD content in 3-year-old Jiegeng was 0.11%, rising to 0.13% in 4-year-old Jiegeng (Ge, Wang, Gui, & Qu, 2017). 2-year-old Jiegeng exhibited suitable root thickness, tenderness, low lignification, and a taste that started bitter and ended sweet, making it generally preferred for culinary use. In contrast, 3-year-old and older Jiegeng were valued for their distinct bitterness, high levels of active ingredients, and medicinal properties, making them more suitable for medicinal purposes (Zhang, Zhang, He, & Huang, 2008; Guo, 2018).

In Japan, *P. grandiflorum* holds a prominent cultural and historical position. As early as the Heian period (794–1192 CE), the *P. grandiflorum* flower was included among the "Seven Autumn Grasses" in the *Manyoshu*, the earliest anthology of *Tanka* poems considered the starting point of Japanese culture and literature. Beyond its ornamental value, the *P. grandiflorum* flower served as inspiration for patterns and family crests throughout history, contributing to its cultural significance. During the Edo period, *P. grandiflorum* roots and rhizomes were combined with *Schizonepetae Herba* (Jingjie in Chinese), *Forsythiae Fructus* (Lianqiao in Chinese), *Mentha Haplocalycis Herba* (Bohe in Chinese) and *Angelicae Sinensis Radix* (Danggui in Chinese).This combination was used to create Jingjie Lianqiao Decoction, which was utilized for the treatment of chronic rhinitis and tonsillitis. Another combination with *Schizonepetae Herba*, *Arctii Fructus* (Niubangzi in Chinese), *Angelicae Pubescentis Radix* (Duhuo in Chinese), Cherry bark (can be replaced by bone skin), *Chuanxiong Rhizoma* (Chuanxiong in Chinese), *Zin-*

Fig. 1. Flowers (A) and seeds (B) of *P. grandiflorum* and Jiegeng (C).

giberis Rhizoma Recens (Shengjiang in Chinese), *Poria* (Fuling in Chinese), *Bupleuri Radix* (Chaihu in Chinese), *Glycyrrhizae Radix* et *Rhizoma* (Gancao in Chinese) resulted in Shiwei Baidu Decoction, which employed to improve and treat chronic urticaria, skin itching, and suppuration. *P. grandiflorum* is also popular in South Korea, where it serves a pharmacological role as a therapeutic agent against bronchitis, asthma, pneumonia, diabetes, and other various diseases (Lee, 1973; Nyakudya, Jeong, Lee, & Jeong, 2014; Takagi & Lee, 1972).

Compared with other countries, *P. grandiflorum* has a longer history of application and is more extensively used in China. Ancient Chinese medical records highlight the widespread use of Jiegeng as an expectorant for relieving throat pain and eliminating mucus. Referred to as "baiyao", "gengcao", and "ji" in ancient Chinese texts, Jiegeng was employed to treat chest pain, abdominal distension, and intestinal tinnitus during the Han Dynasty (Xie, Zhao, Zheng, & Li, 2023). It is recorded in the miscellaneous diseases section of *Treatise on Cold Damage and Miscellaneous Diseases* that the Jiegeng Decoction, made from Jiegeng and licorice, is effective in treating lung abscesses, cough with chest fullness, and vomiting of pus. *Records of Famous Physicians* (Late Han Dynasty, 220–450 CE) suggests that Jiegeng is beneficial for the five viscera and stomach, tonifying *qi* and blood. In the *Essential Subtleties on the Silver Sea* (Tang Dynasty, 682 CE), prescriptions containing Jiegeng were noted for relieving eye pain. *Extension of the Materia Medica* (Song Dynasty, 1116 CE) records Jiegeng's use in treating lung heat, rapid breathing, cough with reverse flow, lung abscess, and lung abscess discharge. The *Compendium of Materia Medica* (Ming Dynasty, 1578 CE) indicates Jiegeng's efficacy in treating oral ulcers, while the *Curative Measures for All Disease* (Ming Dynasty, 1615 CE) highlights its use in treating mastitis, measles, dermatitis, and dysentery. Jiegeng not only has a history of medicinal use but also has been utilized as food for centuries. *Annotations on the Compendium of Materia Medica* (Northern and Southern Dynasties, 536 CE) records its culinary use, stating that it could be cooked and eaten. *The Emergency Materia Medica* (Ming Dynasty, 1406 CE) provides the first specific method of consuming Jiegeng: harvesting the leaves, frying them until cooked, soaking them in water to remove bitterness, washing them thoroughly, and seasoning with oil and salt. The *Chinese Pharmacopoeia Dictionary of 1935* introduces a new method: harvesting tender shoots in spring and cooking them. The ancient medical books on Jiegeng are shown in Fig. 2.

In 2017, *P. grandiflorum* accounted for 44.22% of the total demand, with a food demand ratio of 34.01%. Fueled by demand from Southeast Asia, South Korea, Japan, and other countries, the *P. grandiflorum* export proportion reached 21.77%. Beyond pharmaceutical and food channels, *P. grandiflorum* has expanded its presence in health products, extracts, and traditional Chinese veterinary medicine channels in recent years, with a significant increase in social demand. In 2020, national *P. grandiflorum* consumption was approximately 18 200 tons, projected to reach around 19 600 tons by 2021. Traditionally, *P. grandiflorum* was processed into pickles and cold dishes, modern technology has enabled the production of it-infused sausages, wine, and other products.

3. Chemical constituents

Extensive research has been conducted on the various bioactive components of *P. grandiflorum*. Recent studies have highlighted the primary constituents of *P. grandiflorum*, which include saponins, flavonoids, polysaccharides, phenolic acids, polyacetylenes, sterols, fatty acids, amino acids, and minerals.

3.1. Platycosides

Triterpene saponins constitute the primary bioactive components in Jiegeng. To date, 89 triterpenoid saponins have been identified in Jiegeng (Table 1). These saponins share the oleanolic acid type skeleton, with the majority being disaccharide saponins, indicating their connection to sugar ligands at positions C-3 and C-28. The glycosyl ligands in Jiegeng saponins (JGS) predominantly consist of *D*-glucose, *L*-rhamnose, *L*-arabinose, *D*-xylose, *D*-apiose, and their derivatives (Xu et al., 2021). Categorically, based on different aglycones, these saponins can be classified into five categories (A–E). This classification includes 35 types of polygala acid saponins (A), 22 types of platycodon acid saponins (B), 12 types of platycodon lactone saponins (C), 10 types of platycodon diacid saponins (D), and 10 types of atypical triterpene saponins (E–H) (Fig. 3). Among these, platycodin D (PD) stands out as the most significant

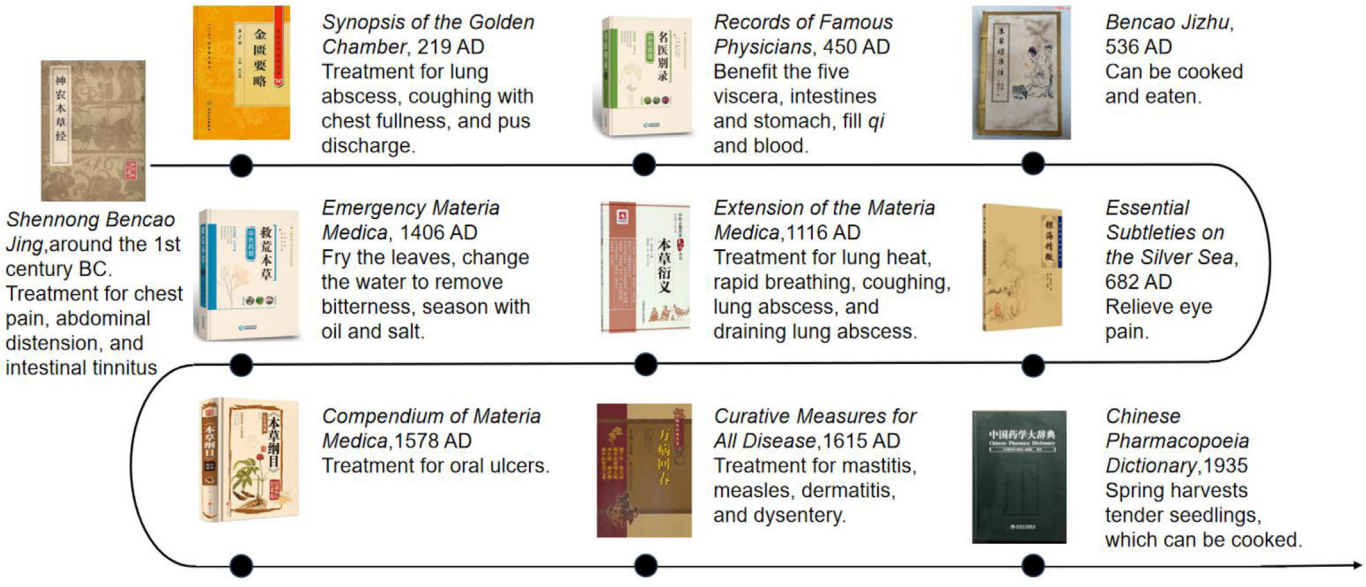


Fig. 2. Ancient medical books of *P. grandiflorum*.

Table 1
Saponins in Jiegeng.

No.	Compounds	Molecular formula	Types	References
1	Platycodigenin	$C_{30}H_{48}O_7$	A	Kubota, Kitatani, & Hinoh, 1969
2	Platycodin A (2″-*O*-Acetyl platycodin D)	$C_{59}H_{94}O_{29}$	A	Kubota et al., 1969
3	Platycodin C (3″-*O*-Acetyl platycodin D)	$C_{59}H_{94}O_{29}$	A	Kubota et al., 1969
4	Platycodin D	$C_{57}H_{92}O_{28}$	A	Ha, Na, Ha, Kim, & Kim, 2010
5	Platycodin D2	$C_{63}H_{102}O_{33}$	A	Choi et al., 2008
6	Platycodin D3	$C_{63}H_{102}O_{33}$	A	Ha, Na, Ha, Kim, & Kim, 2010
7	Platycodin J	$C_{57}H_{90}O_{29}$	A	Liu, Yang, Feng, Jiang, & Zhang, 2019
8	Platycodin K	$C_{59}H_{92}O_{30}$	A	Liu, Yang, Feng, Jiang, & Zhang, 2019
9	Platycodin L	$C_{59}H_{92}O_{30}$	A	Liu, Yang, Feng, Jiang, & Zhang, 2019
10	2′-*O*-Acetyl platycodin D2	$C_{65}H_{104}O_{34}$	A	Na, Ha, Kim, & Kim, 2008
11	2′-*O*-Acetyl platycodin D3	$C_{65}H_{104}O_{34}$	A	Na, Ha, Kim, & Kim, 2008
12	3′-*O*-Acetyl platycodin D2	$C_{65}H_{104}O_{34}$	A	Jeong, Ha, Kim, & Na, 2014
13	3′-*O*-Acetyl platycodin D3	$C_{65}H_{104}O_{34}$	A	Na, Ha, Kim, & Kim, 2008
14	Deapi-platycodin D	$C_{52}H_{84}O_{24}$	A	Ha, Na, Ha, Kim, & Kim, 2010
15	Deapi-platycodin D2	$C_{58}H_{94}O_{29}$	A	Choi et al., 2010
16	Deapi-platycodin D3	$C_{58}H_{94}O_{29}$	A	Ha, Na, Ha, Kim, & Kim, 2010
17	Deapi-3″-*O*-acetyl platycodin D	$C_{54}H_{86}O_{25}$	A	Jeong, Ha, Kim, & Na, 2014
18	Deapi-2″-*O*-acetyl platycodin D2	$C_{60}H_{96}O_{30}$	A	Na, Ha, Kim, & Kim, 2008
19	Platycoside A	$C_{58}H_{94}O_{29}$	A	Fu et al., 2007
20	Platycoside B	$C_{54}H_{86}O_{25}$	A	Fu et al., 2007
21	Platycoside C	$C_{54}H_{86}O_{25}$	A	Fu et al., 2007
22	Platycoside E	$C_{69}H_{112}O_{38}$	A	Nikaido, Koike, Mitsunaga, & Saeki, 1999
23	Platycoside F	$C_{47}H_{76}O_{20}$	A	Fu et al., 2006
24	Platycoside G1(Deapi-platycoside E)	$C_{64}H_{104}O_{34}$	A	He, Qiao, Han, Wang, & Xu, 2005
25	Platycoside G2	$C_{59}H_{96}O_{30}$	A	He et al., 2005
26	Platycoside I	$C_{64}H_{104}O_{33}$	A	Fu et al., 2006
27	Platycoside J	$C_{52}H_{84}O_{23}$	A	Fu et al., 2006
28	Platycoside K	$C_{42}H_{68}O_{17}$	A	Fu et al., 2006
29	Platycoside L	$C_{42}H_{68}O_{17}$	A	Fu et al., 2006
30	Platycoside P	$C_{53}H_{86}O_{25}$	A	Qiu et al., 2019
31	*β*-Gentiotriosyl platycodigenin	$C_{48}H_{78}O_{22}$	A	Na, Ha, Kim, & Kim, 2008
32	3-*O*-*β*-*D*-Gentiotriosyl platycodigenin	$C_{36}H_{58}O_{12}$	A	Zhan, Zhang, Sun, Wu, & Chen, 2012
33	3-*O*-*β*-*D*-Gentiotriosyl platycodigenin methyl ester	$C_{37}H_{60}O_{12}$	A	Ishii, Tori, Tozyo, & Yoshimura, 1981
34	3-*O*-*β*-Gentiotriosyl platycodigenin methyl ester	$C_{43}H_{70}O_{17}$	A	Ishii, Tori, Tozyo, & Yoshimura, 1981
35	3-*O*-*β*-Lentiotriosyl platycodigenin methyl ester	$C_{43}H_{70}O_{17}$	A	Ishii, Tori, Tozyo, & Yoshimura, 1981
36	Platycoside D	$C_{69}H_{112}O_{37}$	B	Nikaido et al., 1999
37	Platycoside G3(Polygalacin D3)	$C_{63}H_{102}O_{32}$	B	He et al., 2005
38	Platycoside H	$C_{58}H_{94}O_{28}$	B	Fu et al., 2006
39	Platycoside N	$C_{53}H_{86}O_{24}$	B	Li et al., 2010
40	Polygalacic acid	$C_{30}H_{48}O_6$	B	Kubota et al., 1969
41	Polygalacin D	$C_{57}H_{92}O_{27}$	B	Ha, Na, Ha, Kim, & Kim, 2010
42	Polygalacin D2	$C_{63}H_{102}O_{32}$	B	Na, Ha, Kim, & Kim, 2008
43	2″-*O*-Acetyl polygalacin D	$C_{59}H_{94}O_{28}$	B	Ha, Na, Ha, Kim, & Kim, 2010
44	2″-*O*-Acetyl polygalacin D2	$C_{65}H_{104}O_{33}$	B	Choi et al., 2010
45	3″-*O*-Acetyl polygalacin D	$C_{59}H_{94}O_{28}$	B	Ha, Na, Ha, Kim, & Kim, 2010
46	3″-*O*-Acetyl polygalacin D2	$C_{65}H_{104}O_{33}$	B	Choi et al., 2010
47	3″-*O*-Acetyl polygalacin D3	$C_{65}H_{104}O_{34}$	B	Jeong, Ha, Kim, & Na, 2014
48	Deapi-polygalacin D2	$C_{58}H_{94}O_{28}$	B	Jeong, Ha, Kim, & Na, 2014
49	Deapi-polygalacin D3	$C_{58}H_{94}O_{28}$	B	Na, Ha, Kim, & Kim, 2008
50	Deapi-2″-*O*-acetyl polygalacin D2	$C_{60}H_{95}O_{30}$	B	Jeong, Ha, Kim, & Na, 2014
51	Deapi-2″-*O*-acetyl polygalacin D3	$C_{60}H_{95}O_{30}$	B	Jeong, Ha, Kim, & Na, 2014
52	Dexyl-2″-*O*-acetyl polygalacin D3	$C_{55}H_{87}O_{25}$	B	Jeong, Ha, Kim, & Na, 2014
53	*β*-Gen-tiobiosy-platycodigenin	$C_{42}H_{68}O_{16}$	B	Na, Ha, Kim, & Kim, 2008
54	3-*O*-*β*-*D*-Glucopyranosyl polygalacic acid	$C_{36}H_{58}O_{11}$	B	Deng et al., 2020
55	3-*O*-*β*-*D*-Laminaribiosyl polygalacic acid	$C_{42}H_{68}O_{16}$	B	Deng et al., 2020
56	Methyl-3-*O*-*β*-*D*-glucopyranosyl polygalacate	$C_{37}H_{60}O_{11}$	B	Ishii, Tori, Tozyo, & Yoshimura, 1981
57	Methyl-3-*O*-*β*-laminaribiosyl polygalacate	$C_{43}H_{70}O_{16}$	B	Ishii, Tori, Tozyo, & Yoshimura, 1981
58	Platycogenic acid A	$C_{30}H_{46}O_8$	C	Kubota et al., 1969
59	Platyconic acid A	$C_{57}H_{90}O_{29}$	C	Choi et al., 2008
60	Platyconic acid B	$C_{59}H_{92}O_{30}$	C	Liu, Yang, Feng, Jiang, & Zhang, 2019
61	Platyconic acid C	$C_{52}H_{82}O_{25}$	C	Liu, Yang, Feng, Jiang, & Zhang, 2019

Table 1 (*continued*)

No.	Compounds	Molecular formula	Types	References
62	Platyconic acid D	$C_{54}H_{84}O_{26}$	C	Liu, Yang, Feng, Jiang, & Zhang, 2019
63	Platyconic acid E	$C_{58}H_{92}O_{30}$	C	Liu, Yang, Feng, Jiang, & Zhang, 2019
64	Platycoside O	$C_{53}H_{84}O_{25}$	C	Li et al., 2010
65	Platyconic acid A methyl ester	$C_{58}H_{92}O_{29}$	C	Choi et al., 2008
66	Methyl platyconate A	$C_{58}H_{92}O_{29}$	C	Ishii, Tori, Tozyo, & Yoshimura, 1981
67	Methyl 2-*O*-methyl platyconate A	$C_{58}H_{94}O_{29}$	C	Ishii, Tori, Tozyo, & Yoshimura, 1981
68	Dimethyl 2-*O*-methyl-3-*O*-*β*-*D*-glucopyranosyl platycogenate A	$C_{39}H_{62}O_{13}$	C	Ishii, Tori, Tozyo, & Yoshimura, 1981
69	Dimethyl 3-*O*-*β*-*D*-glucopyranosyl platycogenate A	$C_{38}H_{60}O_{13}$	C	Ishii, Tori, Tozyo, & Yoshimura, 1981
70	Platycoside Q	$C_{53}H_{82}O_{25}$	D	Qiu et al., 2019
71	Platycoside M-1	$C_{36}H_{54}O_{12}$	D	Fu et al., 2006
72	Platycoside M-2	$C_{47}H_{72}O_{20}$	D	Fu et al., 2006
73	Platycoside M-3	$C_{52}H_{80}O_{24}$	D	Fu et al., 2006
74	Platyconic acid A lactone	$C_{57}H_{88}O_{29}$	D	Choi et al., 2008
75	Platyconic acid B lactone	$C_{63}H_{98}O_{34}$	D	Choi et al., 2010
76	Deapi-platyconic acid A lactone	$C_{52}H_{80}O_{25}$	D	Choi et al., 2008
77	Deapi-platyconic acid B lactone	$C_{58}H_{90}O_{30}$	D	Choi et al., 2010
78	Platycogenic acid A lactone	$C_{30}H_{44}O_{8}$	D	Choi et al., 2008
79	*O*-*β*-*D*-Glucopyranosyl polatycogenic acid A lactone methyl ester	$C_{37}H_{56}O_{12}$	D	Ishii, Tori, Tozyo, & Yoshimura, 1981
80	Platycodonoids A	$C_{29}H_{46}O_{5}$	E	Zhan et al., 2012
81	Platycodonoids B	$C_{35}H_{56}O_{10}$	E	Zhan et al., 2012
82	16-Oxo-platycodin D	$C_{57}H_{90}O_{28}$	E	Li et al., 2007
83	Platycodsaponin A	$C_{42}H_{68}O_{16}$	E	Liu, Yang, Feng, Jiang, & Zhang, 2019
84	Platycogenic acid B	$C_{30}H_{46}O_{8}$	E	Kubota et al., 1969
85	Platycogenic acid C	$C_{30}H_{48}O_{6}$	E	Kubota et al., 1969
86	3-*O*-*β*-*D*-Glucopyranosyl-2*β*,12*α*,16*α*,23,24-pentahydroxy-oleanane-28(13)-lactone	$C_{36}H_{58}O_{13}$	E	Zhang, Liu, & Tian, 2007
87	3-*O*-*β*-*D*-Glucopyranosyl-(1 → 3)-*β*-*D*-glucopyranosyl-2*β*,12*α*,16*α*,23*α*-tetrahydroxy-oleanane-28(13)-lactone	$C_{42}H_{68}O_{17}$	E	Zhang, Liu, & Tian, 2007
88	Platycodon A	$C_{42}H_{68}O_{16}$	E	Ma, Guo, & Zhao, 2013
89	Platycodon B	$C_{41}H_{66}O_{15}$	E	Ma et al., 2013

Note: A: Polygala acid saponins; B: Platycodon acid saponins; C: Platycodon lactone saponins; D: Platycodon diacid saponins; E: Atypical triterpenesaponin.

saponin component among the triterpenoid saponins isolated from Jiegeng.

The 2020 edition of the *Chinese Pharmacopoeia* has set a standard, specifying that the content of PD in Jiegeng should be no less than 0.10%. A study conducted on JGS and PD contents in 36 batches of Jiegeng samples from nine provinces and autonomous regions in China, which revealed that, with the exception of four batches, the PD content in the remaining 32 batches met the specified standard of no less than 0.10%. This suggests that the overall quality of Jiegeng from various production areas is relatively good. Interestingly, the PD content of Zhejiang-produced Jiegeng (average quality score 0.304%) is the highest. However, there is a notable disparity in PD content between different batches in the Zhejiang production area. For instance, the sample from Jinhua City, Zhejiang Province, exhibited the highest PD content at 0.414%, while the PD content in Dongyang City, within the same province, was the lowest at 0.080% (Fang et al., 2016).

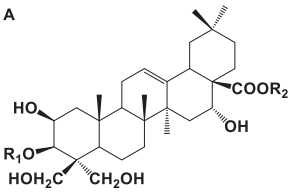
3.2. Flavonoids

To date, a total of 11 flavonoid compounds, encompassing flavones, dihydroflavones, and flavonoid glycosides, have been isolated and identified from *P. grandiflorum* (Table 2) (Ji et al., 2020). The first flavonoid compound obtained from *P. grandiflorum* flowers produced in Japan was delphinidin-dicafeylrubutanol glycoside, categorized as an anthocyanin (Goto, TadaoKondo, Kawahori, & Hattori, 1983). Researchers utilized the UV spectrophotometric method to ascertain the total flavonoid content throughout the annual growth process of *P. grandiflorum*, from germination to withering.

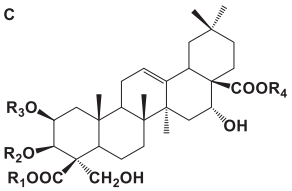
The investigation revealed that the highest flavonoid content was present in the leaves of *P. grandiflorum*, averaging 4.18%. In comparison, the flavonoid content in the flowers measured at 0.99%, and in the fruits, it was 0.86%. Notably, the roots exhibited the lowest flavonoid content, ranging from a mere 0.13% to 0.29%. This suggests that when studying flavonoid compounds in *P. grandiflorum*, it is advisable to focus on the leaves of the plant (Sun et al., 2022). The structures and sources of flavonoids in *P. grandiflorum* are illustrated in Fig. 4.

3.3. Polysaccharides

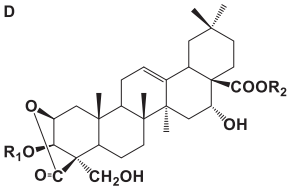
Polysaccharides, a category of biological macromolecules, are widely present in organisms, participating in various biological reactions. Currently, researchers have successfully isolated and identified 21 different polysaccharides from *P. grandiflorum*. The exhibiting molecular weights ranging from 1 900 to 440 000 u majority of these polysaccharides are neutral and composed of fructose, glucose, galactose, arabinose, xylose, and mannose (Sun, Du, Fu, Chu, & Li, 2023). These polysaccharides, known as Jiegeng polysaccharides (JGP), are primarily distributed in *P. grandiflorum*. Throughout the growth stages, from the vigorous growth period to fruiting, the total polysaccharide content in *P. grandiflorum* roots undergoes dynamic changes. Specifically, during the germination



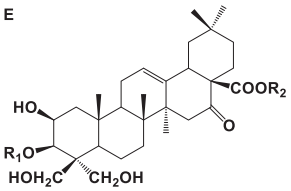
1 R_1=R_2=H
2 R_1=Glc, R_2=Ara^2-Rha(2-OAc)^4-Xyl^3-Api
3 R_1=Glc, R_2=Ara^2-Rha(3-OAc)^4-Xyl^3-Api
4 R_1=Glc, R_2=Ara^2-Rha^4-Xyl^3-Api
5 R_1=GEN, R_2=Ara^2-Rha^4-Xyl^3-Api
6 R_1=GEN, R_2=Ara^2-Rha^4-Xyl^3-Api
7 R_1=GlcA, R_2=Ara^2-Rha^4-Xyl^3-Api
8 R_1=GlcA, R_2=Ara^2-Rha(2-OAc)^4-Xyl^3-Api
9 R_1=GlcA, R_2=Ara^2-Rha(3-OAc)^4-Xyl^3-Api
10 R_1=LAM, R_2=Ara^2-Rha(2-OAc)^4-Xyl^3-Api
11 R_1=GEN, R_2=Ara^2-Rha(2-OAc)^4-Xyl^3-Api
12 R_1=LAM, R_2=Ara^2-Rha(3-OAc)^4-Xyl^3-Api
13 R_1=GEN, R_2=Ara^2-Rha(3-OAc)^4-Xyl^3-Api
14 R_1=Glc, R_2=Ara^2-Rha^4-Xyl
15 R_1=LAM, R_2=Ara^2-Rha^4-Xyl
16 R_1=GEN, R_2=Ara^2-Rha^4-Xyl
17 R_1=Glc, R_2=Ara^2-Rha(3-OAc)^4-Xyl
18 R_1=LAM, R_2=Ara^2-Rha(2-OAc)^4-Xyl
19 R_1=LAM, R_2=Ara^2-Rha^4-Xyl
20 R_1=Glc, R_2=Ara^2-Rha(2-OAc)^4-Xyl
21 R_1=Glc, R_2=Ara^2-Rha(3-OAc)^4-Xyl
22 R_1=Glc^6-Glc^6-Glc, R_2=Ara^2-Rha^4-Xyl^3-Api
23 R_1=Glc, R_2=Ara^2-Rha
24 R_1=Glc^6-Glc^6-Glc, R_2=Ara^2-Rha^4-Xyl
25 R_1=GEN, R_2=Ara^2-Rha
26 R_1=Glc^6-Glc^6-Glc, R_2=Ara^2-Rha^4-Xyl
27 R_1=Glc, R_2=Ara^2-Rha^4-Xyl
28 R_1=LAM, R_2=H
29 R_1=GEN, R_2=H
30 R_1=LAM, R_2=Ara^2-Rha
31 R_1=Glc^6-Glc^6-Glc, R_2=Ara
32 R_1=Glc, R_2=H
33 R_1=Glc, R_2=CH_3
34 R_1=Glc, R_2=CH_3
35 R_1=LAM, R_2=H



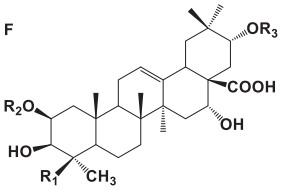
58 R_1=R_2=R_3=R_4=H
59 R_1=R_3=H, R_2=Glc, R_4=Ara^2-Rha^4-Xyl^3-Api
60 R_1=R_3=H, R_2=Glc, R_4=Ara^2-Rha(3-OAc)^4-Xyl^3-Api
61 R_1=R_3=H, R_2=Glc, R_4=Ara^2-Rha^4-Xyl
62 R_1=R_3=H, R_2=Glc, R_4=Ara^2-Rha(2-OAc)^4-Xyl^3-Api
63 R_1=R_3=H, R_2=GEN R_4=Ara^2-Rha^4-Xyl
64 R_1=CH_3, R_2=Glc, R_3=H, R_4=Ara^2-Rha^4-Xyli
65 R_1=CH_3, R_2=Glc, R_3=H, R_4=Ara^2-Rha^4-Xyl^3-Api
66 R_1=CH_3, R_2=Glc, R_3=H, R_4=Ara^2-Rha^4-Xyl^3-Api
67 R_1=CH_3, R_2=Glc, R_3=CH_3, R_4=Ara^2-Rha^4-Xyl^3-Api
68 R_1=CH_3, R_2=Glc, R_3=CH_3, R_4=CH_3
69 R_1=CH_3, R_2=Glc, R_3=H, R_4=CH_3



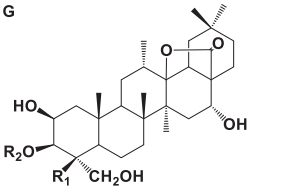
70 R_1=GEN, R_2=Ara^2-Rha
71 R_1=Glc, R_2=H
72 R_1=Glc, R_4=Ara^2-Rha
73 R_1=Glc, R_2=Ara^2-Rha^4-Xyl
74 R_1=Glc, R_4=Ara^2-Rha^4-Xyl^3-Api
75 R_1=GEN, R_4=Ara^2-Rha^4-Xyl^3-Api
76 R_1=Glc, R_4=Ara^2-Rha^4-Xyl
77 R_1=GEN, R_4=Ara^2-Rha^4-Xy
78 R_1=R_2=H
79 R_1=Glc, R_2=CH_3



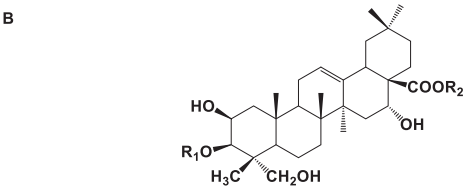
80 R_1=R_2=H
81 R_1=Glc, R_2=H
82 R_1=Glc, R_2=Ara^2-Rha^4-Xyl



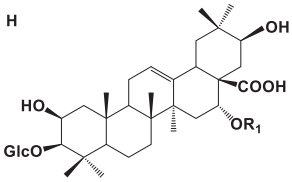
83 R_1=CH_3, R_2=R_3=Glc
84 R_1=COOH, R_2=R_3=H
85 R_1=CH_3, R_2=R_2=R_3=H



86 R_1=CH_3OH, R_2=Glc
87 R_1=CH_3, R_2=LAM



36 R_1=Glc^6-Glc^6-Glc, R_2=Ara^2-Rha^4-Xyl^3-Api
37 R_1=GEN, R_2=Ara^2-Rha(2-OAc)^4-Xyl^3-Api
38 R_1=GEN, R_2=Ara^2-Rha^4-Xyl
39 R_1=GEN, R_2=Ara^2-Rha
40 R_1=R_2=H
41 R_1=Glc, R_2=Ara^2-Rha^4-Xyl^3-Api
42 R_1=LAM, R_2=Ara^2-Rha^4-Xyl^3-Api
43 R_1=Glc, R_2=Ara^2-Rha(2-OAc)^4-Xyl^3-Api
44 R_1=LAM, R_2=Ara^2-Rha(2-OAc)^4-Xyl^3-Api
45 R_1=Glc, R_2=Ara^2-Rha(3-OAc)^4-Xyl^3-Api
46 R_1=LAM, R_2=Ara^2-Rha(3-OAc)^4-Xyl^3-Api
47 R_1=GEN, R_2=Ara^2-Rha(3-OAc)^4-Xyl^3-Api
48 R_1=LAM, R_2=Ara^2-Rha^4-Xyl
49 R_1=GEN, R_2=Ara^2-Rha^4-Xyl
50 R_1=LAM, R_2=Ara^2-Rha(2-OAc)^4-Xyl
51 R_1=GEN, R_2=Ara^2-Rha(2-OAc)^4-Xyl
52 R_1=GEN, R_2=Ara^2-Rha(2-OAc)
53 R_1=GEN, R_2=Ara
54 R_1=Glc, R_2=H
55 R_1=LAM, R_2=H
56 R_1=Glc, R_2=CH_3
57 R_1=LAM, R_2=CH_3



88 R_1=H, R_2=Glc
89 R_1=H, R_2=Xyl

Fig. 3. Chemical structures of triterpenoids isolated from *P. grandiflorum*.

period, it is recorded at 16.94%, rising to 32.12%–45.8% in the vigorous growth period, peaking at 54.1% during the flowering period, and then decreasing to 42.44% in the fruit development period and 35.92% in the late fruiting period. Overall, a dynamic trend of initial increase followed by a subsequent decrease is observed in the polysaccharide content throughout these growth stages (Zhu, Guo, Zhang, & Cao, 2019).

3.4. Phenolic acids

Phenolic components have been detected in both the roots and shoots of *P. grandiflorum*. To date, 14 phenolic compounds have been identified, with coniferyl palmitate and coniferyl oleate found in the roots (Lee, Yoon, Kim, & Lim, 2004), and 12 phenolic compounds were purified from the aerial parts of *P. grandiflorum*. These

Table 2
Flavonoids found in flowers, seeds and aerial parts of *P. grandiflorum*.

No.	Compounds	Molecular formulas	Sources	References
90	Platyconin	$C_{63}H_{74}O_{37}$	Flowers	Inada, Murata, Somekawa, & Nakanishi, 1992
91	Delphinidin-3-rutinoside-7-glucoside	$C_{33}H_{42}O_{16}$	Flowers	Jin, 2007
92	(2*R*, 3*R*)-Taxifolin	$C_{15}H_{12}O_7$	Seeds	Inada et al., 1992
93	Flavoplatycoside	$C_{27}H_{32}O_{16}$	Seeds	Inada et al., 1992
94	Quercetin-7-*O*-glucoside	$C_{21}H_{20}O_{12}$	Seeds	Inada et al., 1992
95	Luteolin-7-*O*-glucoside	$C_{21}H_{20}O_{11}$	Seeds, aerial parts	Inada et al., 1992
96	Quercetin-7-*O*-rutinoside	$C_{27}H_{30}O_{16}$	Seeds	Inada et al., 1992
97	Apigenin-7-*O*-glucoside	$C_{21}H_{20}O_{10}$	Aerial parts	Mazol et al., 2004
98	Apigenin	$C_{15}H_{10}O_5$	Aerial parts	Mazol et al., 2004
99	Luteolin	$C_{15}H_{10}O_7$	Aerial parts	Mazol et al., 2004
100	Platycoside	$C_{20}H_{20}O_7$	Seeds	Inada et al., 1992

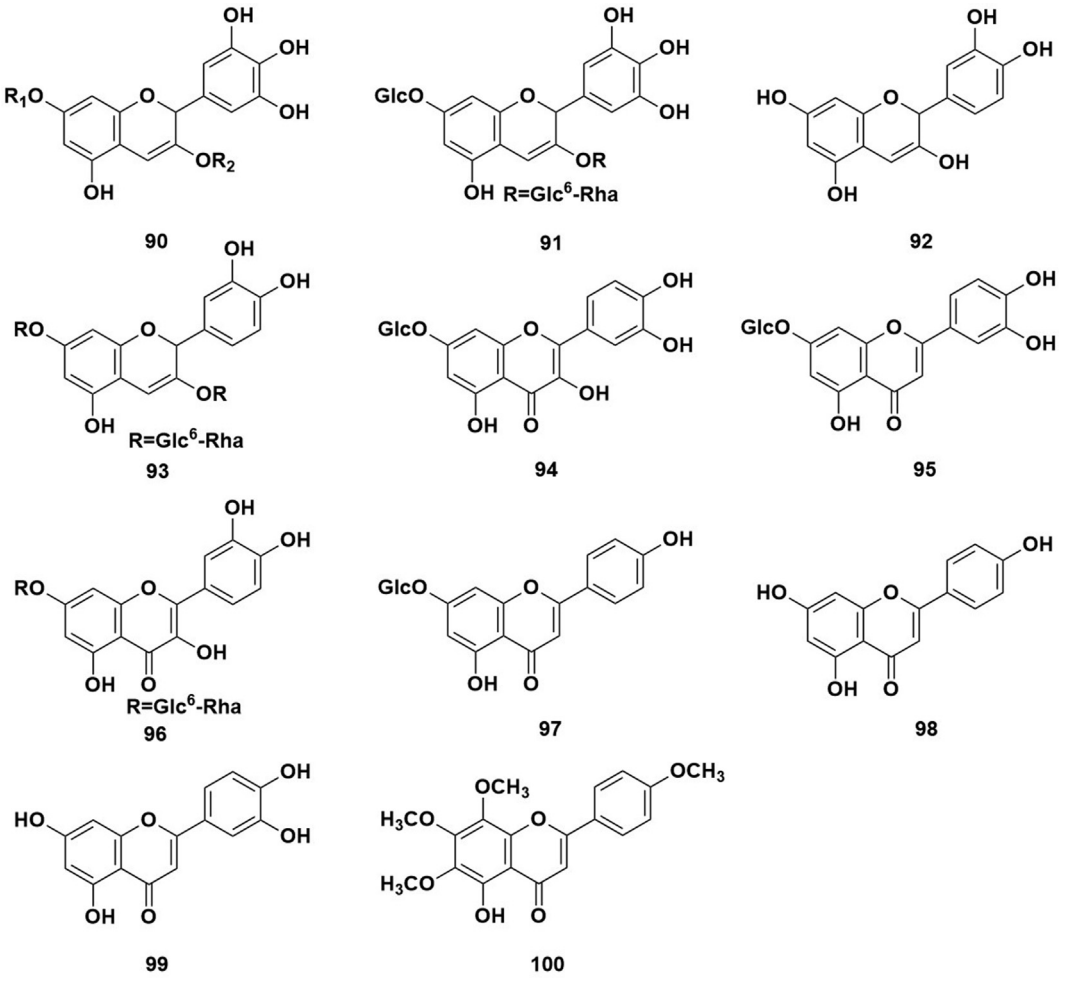


Fig. 4. Chemical structures of flavonoids isolated from *P. grandiflorum*.

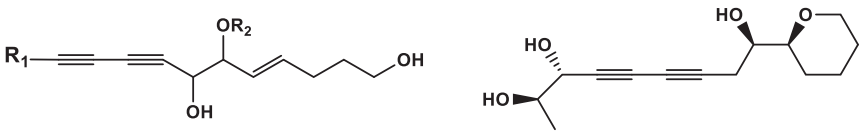
aerial phenolic compounds include caffeic acid, 3,4-dimethoxycinnamic acid, ferulic acid, isoferulic acid, *m*-coumaric acid, coumaric acid, *p*-hydroxybenzoic acid, α-resorcylic acid, 2,3-dihydroxybenzoic acid, 2-hydroxy-4-methoxybenzoic acid, homovanillic acid, and chlorogenic acid (Mazol, Gleńsk, & Cisowski, 2004).

3.5. Polyacetylene

Six polyacetylene compounds have been successfully isolated from *P. grandiflorum* (Fig. 5). Among these, three polyacetylene compounds—lobetyol, lobetyolin, and lobetyolinin—were extracted from *P. grandiflorum* (Tada, Shimomura, & Ishimaru, 1995). Additionally, platetyolin A and platetyolin B were separated from *P. grandiflorum* using HPLC (Chen et al., 2018). More recently, a novel polyacetylene, isolobetyol, was discovered in *P. grandiflorum* (Li, 2022).

3.6. Other compounds

Various compounds, including sterols, fatty acids, amino acids, and mineral elements, have also been identified in *P. grandiflorum*.



101 R_1=CH=CHCH$_3$(*trans*), R_2=H
102 R_1=CH=CHCH$_3$(*trans*), R_2=Glc
103 R_1=CH=CHCH$_3$(*trans*), R_2=Gen
104 R_1=CCCH$_3$, R_2=Glc
105 R_1=CH=CHCH$_3$(*cis*), R_2=Glc

106

Fig. 5. Chemical structures of polyacetylene isolated from *P. grandiflorum*.

Five sterols have been recognized in *P. grandiflorum*, namely spinasterol, α-spinasteryl-3-*O*-β-*D*-glucoside, betulin, β-sitosterol, and δ-7-stigmastenone-3 (Zhang et al., 2015). Through the Soxhlet extraction method, 34 types of fatty acids were identified in *P. grandiflorum* oil, comprising 15 unsaturated and 19 saturated fatty acids. Notably, linoleic acid content was the highest at 42.79%, followed by linolenic acid (14.02%) and palmitic acid (13.71%) (Gong & Wang, 2010).

In terms of amino acids, *P. grandiflorum* contains a total of 17, with eight being essential. The most abundant amino acids include arginine (23.54%), proline (20.28%), and glutamic acid (23.08%), collectively constituting almost 70% of the total amino acid content (Zhang et al., 2019). Furthermore, *P. grandiflorum* encompasses over 22 inorganic elements, with eight essential trace elements: Cu, Zn, Ni, Mn, Cr, Sr, Fe, and V (Zhou, 2017).

4. Pharmacological activities

P. grandiflorum is abundant in various chemical components, possessing high medicinal and nutritional value that proves beneficial to the human body. The primary functions of *P. grandiflorum* include promoting lung health, soothing the throat, and alleviating phlegm symptoms. Modern pharmacological studies have validated its diverse pharmacological activities, encompassing antitumor, anti-oxidation, anti-obesity, as well as liver and heart protection. These findings underscore the significant clinical applications and research potential of *P. grandiflorum*, as outlined in Table 3, which details the main pharmacological activities and active compounds of *P. grandiflorum*.

4.1. Antitussive and antiphlegm activity

Jiegeng boasts a long history of clinical use in the treatment of respiratory diseases, with its main functions being lung ventilation and phlegm expulsion. Cough and sputum represent primary clinical symptoms in respiratory diseases, including upper respiratory tract infections, asthma, chronic obstructive pulmonary disease, lung cancer, and coronavirus pneumonia (COVID-19), often marked by recurrent attacks (Wang et al., 2020). Respiratory diseases frequently arise due to excessive mucus secretion or inadequate mucus clearance. The potential mechanisms of the antitussive and expectorant effects of Jiegeng include inhibiting excessive mucin secretion in the airways, reducing inflammation, and suppressing the secretion of inflammatory cytokines (Fig. 6). Notably, research utilizing the guaifenesin red experimental method in a mouse model of cough induced by ammonia water demonstrated Jiegeng aqueous extract (JGAE) significantly inhibited cough frequency induced by concentrated ammonia water in mice. Furthermore, it significantly increased phenol red excretion in the trachea of mice (Zhu et al., 2015). Compared with the model group (28.0 ± 11.8) s, the cough latency period of mice in the low-dose group and high-dose group of JGAE was prolonged to (52.0 ± 10.7) s and (96.0 ± 32.3) s respectively, which indicated that the cough latency period was significantly prolonged after the treatment of JGAE. In addition, tracheal phenol red secretion in both the low-dose (1.40 ± 0.28) μg/mL and high-dose groups of JGAE (1.90 ± 0.31) μg/mL significantly increased ($P < 0.05$ or $P < 0.01$) compared to that of the blank control group (0.63 ± 0.17) μg/mL. This increase in respiratory secretions aids in thinning thick spu-

Table 3
Pharmacological activities and active ingredients of *P. grandiflorum*.

Pharmacological activities	Related cytokines and signaling pathways	Active ingredients
Antitussive and antiphlegm activity	TNF-α, IL-6, IL-1β, iNOS, NF-κB, ROS-PKCδ-MAPK	Total extracts Platycosides Polysaccharides
Anti-cancer activity	Casepase-8, Caspase-9, Casepase-3, Bcl-2, Bax, PI3K, AKT, mTOR, c-Myc, CDK6, EphA2, E-cadherin	Total extracts Platycosides
Anti-inflammatory activity	PI3K/AKt, IL-8, IL-4, IL-5, IL-13 CRP, TNF-α, IL-1β, AMPK, NF-κB, Caspase-3, Bax, Nrf2, Bcl-2, LXRα	Total extracts Platycosides Polysaccharides
Immunostimulatory activity	p-65, ERK, JNK, NF-κB, MAP	Total extracts Platycosides Polysaccharides
Antioxidation activity	SOD, NO, iNOS	Total extracts Polysaccharides Phenolic acids
Anti-obesity and antidiabetic activity	PPARc, C/EBPa, AMPK, SREBP-1c, CPT1a, HSL, UCP1, SIRT1/CaMKKβ	Total extracts Platycosides Flavonoids
Hepaoprotective and cardiovascular activity	Bcl-2, Bax, Bcl-xL, Caspase-3	Total extracts Polysaccharides

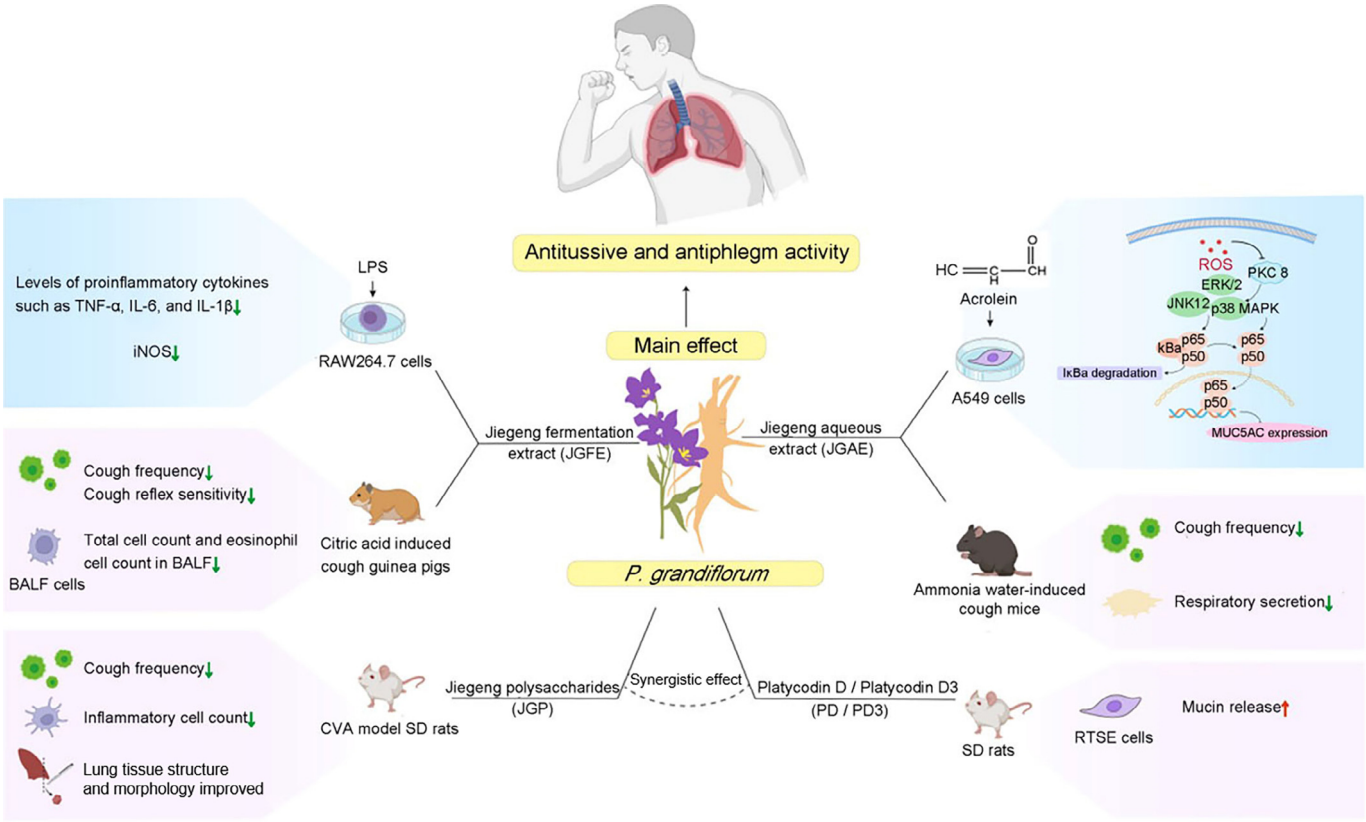


Fig. 6. Antitussive and antiphlegm activity of *P. grandiflorum*.

tum attached to the respiratory mucosa, facilitating its detachment from the airway wall and promoting expectoration.

Mucin overproduction, a characteristic feature of chronic airway diseases, was addressed in an *in vitro* experiment. A549 cells induced with acrolein, a toxin found in cigarette smoke, exhibited increased expression of airway mucin 5, subtypes A and C (MUC5AC). JGAE demonstrated inhibitory effects on acrolein-induced ROS production in A549 cells, inhibiting NF-κB activation through the ROS-PKCδ-MAPK signaling pathway. Additionally, it decreased MUC5AC expression in the airway, suggesting it has therapeutic effects in chronic airway diseases (Choi et al., 2011).

Different processing methods have varying effects on the antitussive properties of Jiegeng. Intriguingly, honey processing was found to enhance the anti-cough effect of Jiegeng. Research demonstrated that the aqueous extract of honey-baked Jiegeng, prepared with a water-to-honey ratio of 1: 2.5 at 90 °C for 2 h, exhibited a prolonged cough latency (35.38 ± 9.24) s and a reduced cough frequency (15.13 ± 5.3 times every 2 min) compared to pure Jiegeng (Huang, Zhong, Zhong, Zhang, & Zhu, 2020). Furthermore, the fermented Jiegeng extract (JGFE) was observed to augment PD activity. In an animal model of citrate-induced cough reflex, JGFE-treated groups (at 200 and 400 mg/kg, respectively) significantly reduced the number of coughs compared to the vehicle-treated group, inhibiting cough reflex sensitivity by 25% (Lee et al., 2020).

Moreover, Jiegeng saponin (JGS) was found to enhance antitussive and expectorant effects through gut microbiota metabolism, aligning with the TCM theory of the interconnectedness of the lungs and large intestine. Metabolomic analysis revealed that both the JGS fraction and its active microbial metabolites regulated linoleic acid, arachidonic acid, and glycerophospholipid metabolism, contributing to antitussive and expectorant activities (Zhang et al., 2021). GPD 682, a key secondary saponin metabolite (SSM) in JGS, demonstrated efficacy in improving drug distribution *in vitro* and *in vivo*, presenting potential as an adjuvant for enhancing drug delivery to lung tissues and improving the treatment of respiratory diseases (Shen et al., 2019). Results indicated significant differences in cough and expectorant activities among various ingredients (Zhang, Chai, Hou, Zhao, & Meng, 2022). Notably, platycosides D2, PD, and polysenoside D2 ranked highest among the 17 chemical components related to expectorant activity, while 12 components of Jiegeng were associated with antitussive activity.

Components such as polygalacin D, deapioplatycodin D, and PD, which are highly associated with antitussive activity, exhibit low expectorant activity. Only platycosides D3, G3, and PD demonstrate both antitussive and expectorant effects. Notably, the most abundant component, PD, is neither the most effective in suppressing coughs nor the most efficient in eliminating phlegm. *In vitro* studies indicate that mucin production in airway epithelial cells (RTSE cells) increased by 252.7% and 370.2% for PD and platycodin D3 at a concentration of 200 mg/L, respectively, compared to a positive control group. *In vivo*, platycodin D3 (20 mg/L) exhibited a greater increase in mucin release than ambroxole (200 mg/L) in SD rats (Shin, Lee, Lee, Choi, & Ko, 2002). Cough variant asthma (CVA) induced by OVA stimulation in elderly rats revealed a significant reduction in cough frequency and inflammatory cells in the lungs of rats in the low- and high-dose groups (0.75 g/mL, 3 g/mL) of JGP compared with the model group. The expression of inflammatory-related proteins matrix metalloproteinase 9 (MMP-9), tissue inhibitor of metal protease 1 (TIMP-1), eotaxin, transforming growth factor β1 (TGF-β1), and nuclear factor-κB p65 (NF-κBp65) was also decreased. Additionally, lung tissue pathology showed a reduction in inflammatory cells in the low- and high-dose JGP groups. The lung tissue structure of the high-dose

group significantly improved, with reduced mucosal edema and less common airway narrowing. This suggests that JGP significantly alleviated the development of CVA in elderly rats (Lin et al., 2023). Furthermore, in a chronic bronchitis model induced in rats by inhaling 2% (volume percentage) sulfur dioxide (SO_2) for 30 min daily for 15 consecutive days. PD and PD + JGP were administered orally. After 15 d of continuous smoking and administration by PD (2 mg/kg, group PD), JGP (75, 150, 300 mg/kg, groups $JGP_{L/M/H}$) and PD + JGP (groups PD-$JGP_{L/M/H}$) respectively, both the PD group and PD + JGP groups exhibited significant reductions in lung tissue acid mucin secretion, mucin 2 expression, and TNF-α expression compared to the model group. This implies that PD has a therapeutic effect on chronic bronchial inflammation, and the combined effect with JGP is enhanced, suggesting PD + JGP has a synergistic role in chronic bronchitis treatment (Liu et al., 2022).

The main effects of *P. grandiflorum* are cough relieving and expectorant. The figure summarizes the active ingredients in the available literature that contribute to its antitussive and phlegm removal. JGFE can significantly reduce the decrease cough frequency, sensitivity of the cough reflex, the number of eosinophils and total cells in BALF from cough reflex-induced guinea pigs. JGAE can inhibit the production of ROS and NF-κB activation through the ROS-PKCD-MAPK signaling pathway, reduce the expression of MUC5AC, and reduce the frequency of cough and respiratory secretions in mice. PD and PD3 increase the secretion of mucin in the airway epithelial cells of rats, which is beneficial for sputum excretion. JGP can reduce the frequency of cough and inflammatory cell count, and improve the pathological state of lung tissue in asthmatic rats. Furthermore, PD and JGP have synergistic effects in the treatment of chronic bronchitis.

4.2. Anticancer activity

Jiegeng demonstrates notable anticancer activity across various malignant tumors, including ovarian cancer, endometrial cancer, cervical cancer, prostate cancer, lung cancer, and stomach cancer. This effect is achieved through mechanisms such as inducing cancer cell apoptosis and autophagy, inhibiting tumor cell development, immune regulation, combined use with other drugs, among others (Zhang et al., 2020).

In ovarian cancer cells SKOV3, JGAE promotes cyt-c release, activates Caspase-8 and Caspase-9, downregulates Bcl-2, upregulates Bax, and induces apoptosis through a mitochondrial-mediated pathway (Hu et al., 2010). For endometrial cancer, PD inhibits phosphoinositide 3-kinase (PI3K), protein kinase B (AKT), mammalian target of rapamycin (mTOR), nuclear proto-oncogenes (c-Myc), cyclin dependent kinase 6 (CDK6), Vimentin, Snail mRNA and protein expressions, promotes E-cadherin expression, downregulates phosphorylated AKT (p-AKT) and phosphorylated mTOR (p-mTOR) levels, thereby inhibiting cell proliferation, invasion, and migration (Bao, Sun, Qiao, & He, 2022). In a cervical cancer mouse model, U14 cells injected into the peritoneal cavity show tumor inhibition rates of 14.81%, 33.74%, and 44.03% for low (20 mg/kg), medium (40 mg/kg), and high (60 mg/kg) doses of JGP, respectively. Medium- and high-dose JGP groups increase expression levels of Bax and p19ARF proteins and reduce mutant p53 protein expression, suggesting JGP has a significant inhibition of tumor growth and apoptosis induction (Lu, Yang, Jia, & Zhao, 2013). For primary human prostate cancer cells (RC-58T/h/SA#4), JGS inhibits proliferation and induces apoptosis in a dose-dependent manner through Caspase-dependent and Caspase-independent mechanisms (Lee et al., 2013). Jiegeng, commonly used as a lung medication, enhances the effects of other drugs on lung cancer. A549-Luc cells were implanted into the lungs of female nude mice via thoracentesis to establish a xenograft tumor model. In a xenograft tumor model, compared to the DDP group, the tumor inhibition rates of the low-, medium-, and high-dose groups of DDP + JGAE were increased by 19.18%, 39.76%, and 13.92%, respectively (Li et al., 2019). Therefore, the combination therapy group demonstrated significantly stronger anticancer effects than the DDP alone group. *In vitro*, A549 cells were divided into control, platycodin, and combination treatment groups, and the expressions of ephrin type-A receptor 2 (EphA2)/AKT/mTOR-related proteins were detected by western blotting after 48 h of treatment. Compared to the control group, the expression of EphA2 and p-EphA2 proteins in the platycodin and combination groups was significantly decreased ($P < 0.01$). The p-AKT and mTOR expression levels were significantly downregulated in the platycodin group ($P < 0.01$) (Gong & Wang, 2010). PD exhibited better inhibitory activity against gastric cancer (GC) cell lines than gastric epithelial cells (GES-1) against gastric mucosal cell lines and non-tumor cell line. PD significantly inhibits GC cell growth and reproduction by downregulating c-Myc expression in a dose-dependent manner. Myc degradation leads to the inactivation of the p21 gene/cyclin-dependent kinase (CDK 2) pathway, which in turn induces cell cycle arrest and subsequent apoptosis (Xu et al., 2023).

4.3. Anti-inflammatory activity

Jiegeng has anti-inflammatory activity and is widely used in treating various inflammatory diseases, such as acute lung injury, allergic airway inflammation, rheumatoid arthritis, colitis, chronic obstructive pneumonia, and asthma.

JGAE (1.51 g/kg/d, 3.775 g/kg/d, and 7.55 g/kg/d) can significantly reduce the expression of inflammatory factors IL-1β, IL-6, and TNF-α in the lung tissue of mice with acute lung injury (ALI) induced by LPS, and upregulate Bcl-2 while downregulating Bax. In conclusion, JGAE can reduce the inflammatory response to ALI by inhibiting the PI3K/Akt signaling pathway and inhibiting cell apoptosis (Zhou et al., 2023). A previous study showed that in LPS/BLE-induced MLE-12 cells, PD dose-dependently reduced the lung wet/dry weight ratio, total white blood cell count, neutrophil percentage in BALF, and the activity of lung tissue myeloperoxidase (MPO). In *in vitro* experiments, PD intervention significantly downregulates the TNF-α, IL-6, NF-κB, Caspase-3, and Bax levels in ALI cells of mice, while significantly upregulating Bcl-2 expression. It has been speculated that PD is the main active ingredient in JGAE, which plays a protective role against ALI (Tao et al., 2015). In animal experiments, Jiegeng ethanol extract (JGEE) could control inflammatory cell infiltration, endoplasmic reticulum stress, and NF-κB signaling transduction in asthma model mice induced by house dust mite extract. JGEE can inhibit the expression of inflammatory cytokines and MU5AC, and can be used as a drug for treating and preventing house dust mite-related allergic airway inflammation (Lee, Lee, Kim, & Chae, 2019). High JGEE concentrations (20 mg/kg and 40 mg/kg) effectively reduced the degree of foot swelling in a rat model of rheumatoid arthritis. After injecting a type II collagen solution into the plantar skin, tail root, and back of the left hind foot of rats to induce rheumatoid arthritis, the rats were orally administered low (20 mg/kg), medium (30 mg/kg), or high (40 mg/kg) doses of JGEE for 20 d. Compared to the model group arthritis index (8.11), the arthritis index in the low-, medium-, and high-dose JGEE groups decreased to 5.61, 5.22, and 4.37, respectively, indicating a reduction in inflammation severity in rheumatoid arthritis rats. The higher the JGEE concentration was, the more significant the decrease was in inflammatory factors IL-8, CRP, and TNF-α levels, thereby exerting an anti-inflammatory effect (Yang & Wang, 2020; Wang, Wang, Wang, Shi, & Wu, 2022). JGFE was obtained by using *Lactobacillus rhamnosus* 217-1 to ferment Jiegeng powder. The JGFE intervention suppressed the phenomenon of weight loss in mice with ulcerative colitis induced by 3% DSS, and the mRNA expression levels of TNF-α ($P < 0.01$,

$P < 0.01$), IL-6 ($P < 0.01$, $P < 0.01$), and IL-1β ($P < 0.05$, $P < 0.01$) were significantly downregulated compared to the model group. JGFE can inhibit the expression of the NF-κB signaling pathway and NLRP3 inflammasome by activating the AMPK pathway and reducing pro-inflammatory cytokine release, thereby alleviating ulcerative colitis in mice. Researchers also found that using DSS to construct an ulcerative colitis mouse model, PD treatment can not only reduce the levels of pro-inflammatory factors TNF-α, IL-6, and IL-β but also regulate the M1 phenotype of macrophages to the M2 phenotype. This suggests that PD improves ulcerative colitis by activating the AMPK pathway and regulating macrophage phenotypes (Guo, Meng, Wang, & Li, 2021). Cigarette smoke is a toxic mixture and long-term exposure to cigarette smoke can cause chronic obstructive pneumonia (COPD). Mice were exposed to smoke from ten 3R4F study cigarettes, and lung tissues were collected for analysis after five consecutive days of intraperitoneal PD injection (20, 40, and 80 mg/kg) 2 h before exposure in the treated groups. It was found that treatment with PD dose-dependently suppressed CS-induced lung histopathological changes, inhibited the NF-κB signaling pathway, and reduced the number of inflammatory factors. Jiegeng plays a protective role against cigarette smoke-induced pulmonary inflammation by activating the Nrf2 signaling pathway (Gao, Guo, & Yang, 2017). In an OVA-induced asthma mouse model, JGP dose-dependently decreased lung resistance, increased dynamic lung compliance, and reduced the Eotaxin, IL-4, IL-5, and IL-13 levels in BALF, as well as IgE in the serum. The expressions of inflammatory cells, mucus secretion, goblet cell proliferation, and airway remodeling-related proteins in the lung tissue were significantly reduced (Fig. 7) (Yao, Chen, & Li, 2020).

The figure summarizes the effective components of *P. grandiflorum* in exerting anti-inflammatory effects, the diseases involved, and the relationship with cytokines. JGAE reduces inflammatory factors IL-1β, IL-6, and TNF-α in mice with ALI. It also upregulates Bcl-2, downregulates Bax, and inhibits the PI3K/Akt signaling pathway to suppress cell apoptosis. JGEE reduces inflammatory factors IL-8, CRP, and TNF-α in rats with rheumatoid arthritis. JGFE reduces pro-inflammatory cytokines in mice with ulcerative colitis, activates the AMPK pathway, inhibits the NF-κB signaling pathway, and suppresses the expression of NLRP3 inflammasomes. PD alleviates ulcerative colitis in mice by modulating macrophage phenotypes, inhibiting the secretion of inflammatory factors in mice with chronic obstructive pulmonary disease, reducing NF-κB pathway activation, and activating the Nrf2 signaling pathway. JGP has anti-inflammatory effects in asthmatic mice by reducing the levels of specific inflammatory factors in BALF and serum. It also decreases the production of inflammatory cells in lung tissue and related proteins.

4.4. Immunostimulatory activity

Immune regulation plays an important role in maintaining health. Its basic mechanism is to activate macrophages and body systems, promote humoral and cellular immune responses, and secrete relevant immunoactive factors to complete immune regulation and improve health (Chai et al., 2021).

After 24 h of fermentation with Jiegeng and *Lactobacillus casei*, the hydrolyzed fermentation extract significantly increased the phosphorylation of p-65, ERK, and JNK, as well as the ratios of p-p65/p65, p-ERK/ERK, and p-JNK/JNK. It can exert immune-stimulating activity through the MAPK and NF-κB signaling pathways (Jung et al., 2022). In addition, Jiegeng exhibits immunomodulatory activities. $CD4^+$ T helper (Th) cells and $CD8^+$ T cytotoxic (Tc) lymphocytes are the two common T lymphocytes essential for adaptive immunity. JGP significantly promotes lymphocyte cycle progression, increases $CD4^+$ and $CD8^+$ T cell levels, and enhances immune functions *in vitro* (Zhao et al., 2017). JGS also has immune functions. OVA was injected subcutaneously into ICR mice for subcutaneous immunity experiments. PD and PD3 significantly promoted mitogenic and OVA-induced splenocyte proliferation in OVA-immunized mice. They also increased the OVA-specific IgG, IgG1, IgG2a, and IgG2b levels in the serum of OVA-immunized mice, thereby enhancing their immune responses (Xie, Ye, Sun, & Li, 2008).

4.5. Antioxidant activity

P. grandiflorum has good antioxidant activity, which varies in different parts of the body. The *n*-butyl alcohol extract from Jiegeng by saturated had a scavenging rate of 98.03% for DPPH free radicals and 84.30% for ABTS free radicals (Ma et al., 2021). Previous studies have demonstrated that the seeds, roots, stems, and leaves have antioxidant activity. DPPH and ABTS radical scavenging methods are frequently used to assess the antioxidant activity of various food products. The half-inhibitory concentration of Jiegeng for DPPH and ABTS free radicals is 4.07 mg/mL and 2.10 mg/mL, while the half-inhibitory concentration of *P. grandiflorum* seeds is only 0.13 mg/mL and 0.04 mg/mL, indicating that the seeds of *P. grandiflorum* have stronger antioxidant activity than the Jiegeng (Kim, Yoon, Lee, & Imm, 2020).

It is worth noting that the pruned stems, leaves, and flowers of *P. grandiflorum* also showed strong antioxidant activity during the

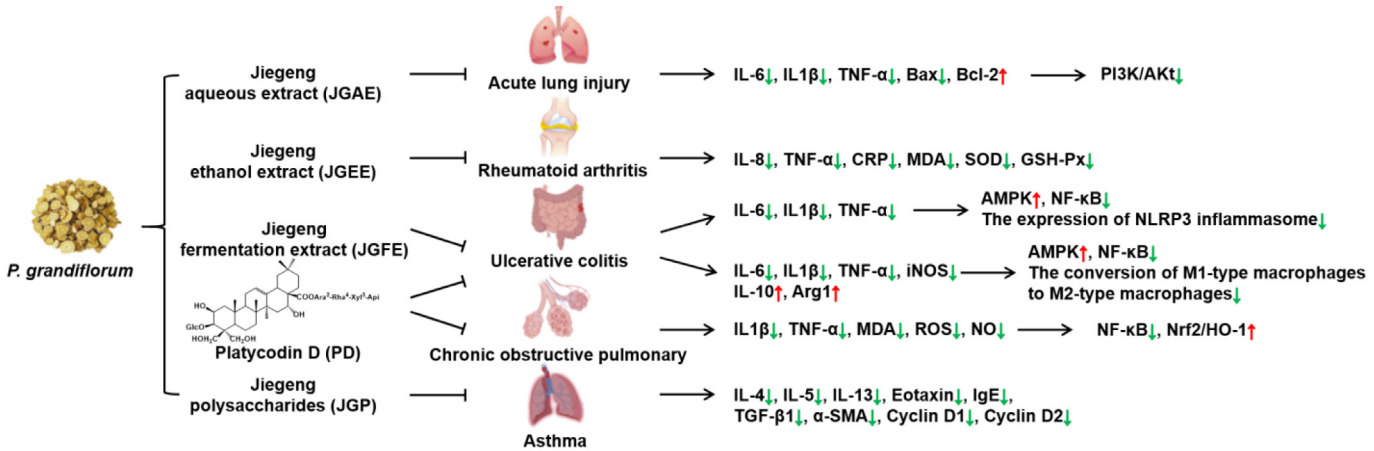


Fig. 7. Anti-inflammatory effects of some chemical constituents from *P. grandiflorum*.

growth process. Further identification of the active ingredients revealed the presence of phenolic compounds, specifically paeonol-7-*O*-glucoside, which play a major role in antioxidant activity (Jeong, Ha, Kim, & Na, 2010). JGP also exhibits good antioxidant activities. The ABTS and DPPH free radical-scavenging performances of pure JGP were better than those of crude JGP (Dong et al., 2018). When the concentration of vitamin c (Vc) was 5 mg/mL, the DPPH free radical scavenging rate was 99.54%, the crude JGP was 64.75%, and the pure JGP was 76.65% with the same concentration. Meanwhile, the crude JGP (5 μg/mL) and pure JGP (5 μg/mL) had weak ABTS free radical scavenging ability, and the difference was not significant, which were 21.87% and 23.94%, respectively, when ABTS free radical scavenging rate of Vc reached nearly 100% with the same concentration. In another study, crude JGP was further purified using complex enzyme extraction to obtain JGP-W-1. *In vitro* antioxidant experiments showed that the ability of JGP-W-1 to scavenge DPPH, ABTS and hydroxyl radicals was 57.3%, 66.5% and 94.7% of Vc, respectively. Although the total reducing power of JGP-W-1 is weaker than that of Vc under the same conditions, it also has some antioxidant capacity (Li, Fang, Zhang, & Xie, 2023).

4.6. Anti-obesity and antidiabetic activity

P. grandiflorum plays an anti-obesity role in fat production and metabolic processes. In an obese mouse model induced by a high-fat diet, the intervention of JGAE reduced 7.5% weight gain, downregulated lipogenic gene expression in liver and white adipose tissue, and increased lipolytic gene expression. It can also prevent obesity in mice by inhibiting the intestinal absorption of dietary fat and reducing triglyceride levels in the liver (Ahn, Kim, Kang, & Lee, 2012; Hwang et al., 2019). JGEE reduces the free fatty acid concentration in the blood of obese mice, increases fecal lipid excretion, and causes browning of white adipose tissue by increasing the uncoupling protein 1 (UCP1) level, increasing the thermogenic gene expression, promoting lipolysis, and inhibiting lipogenesis (Hwang et al., 2019; J.I. Kim et al., 2017; Y.J. Kim, Ryu, Choi, & Choi, 2019). PD inhibits lipogenesis in liver tissue by activating the AMPK signaling pathway in HepG2 cells via SIRT1/CaMKKβ (Hwang et al., 2013). Furthermore, the purified neutral polysaccharide derived from Jiegeng (JGNP), effectively increased the species diversity of the intestinal microbiota and improved the intestinal microbiota imbalance in mice fed a high-fat diet (Song, Liu, Hao, Zhai, & Chen, 2023). In addition, Jiegeng flavonoids have anti-diabetic activity. Jiegeng flavonoids can promote insulin secretion in diabetic zebrafish by closing the KATP pathway, and the aerial part of *P. grandiflorum* has stronger anti-diabetic activity than its root (Nam et al., 2023). Studies have shown that the combination of Jiegeng, celery, and green tea extracts has a more potent anti-obesity effect than a single extract. Simultaneously, the combination of Jiegeng, celery, and green tea extracts reduced liver injury by reducing serum glutamic oxaloacetic transaminase (GOT) and glutamic-pyruvic transaminase (GPT) levels and upregulating liver antioxidant enzymes (Cho et al., 2020).

4.7. Hepatoprotective and cardiovascular activity

In recent years, plant carbon dots extracted from traditional Chinese herbs have received extensive attention in many fields because of their excellent biological activities. Researchers have found that Jiegeng carbon dots (Jiegeng-CDs) extracted through dehydration, calcination, and carbonization have protective effects on the liver of mice with bilirubin-induced hyperbilirubinemia. When liver cells are damaged, the MDA levels generally increase. However, after pretreatment with Jiegeng-CDs, the superoxide dismutase (SOD), glutathione (GSH), and catalase (CAT) levels significantly increased, whereas the MDA level significantly decreased, indicating that Jiegeng-CDs can effectively enhance the body's antioxidant capacity and protect the liver of mice with hyperbilirubinemia (Chen et al., 2023). Jiegeng possesses hepatoprotective properties in various toxin-induced hepatitis models. JGP has a protective effect on LPS/*D*-galactose (*D*-GalN)-induced acute liver injury in mice. H&E staining showed that JGP can reduce liver cell injury, reduce aspartate aminotransferase (AST), alanine aminotransferase (ALT), superoxide dismutase (SOD) activities, and reduce liver cell injury. And it has a protective effect against *D*-Gal *N*-induced acute liver injury in mice by downregulating Caspase-3 and Bax and upregulating Bcl-2 (Qi et al., 2021). Palmitic acid can stimulate AmL-12 cells to establish a cell model of non-alcoholic fatty liver disease (NAFLD). After treating the cells with PD (1 μmol/L) for 24 h, the levels of ROS and protein expression of p62 were significantly reduced, while the ratio of microtubule-associated proteins light chain 3 (LC3) – phosphatidylethanolamine conjugate to cytosolic form was increased. These results indicated that PD improves NAFLD by reducing oxidative stress and cellular autophagy, thereby protecting the liver (Wen et al., 2022).

Jiegeng extract exhibited cardioprotective activity. In a study on its cardioprotective mechanism in patients with early breast cancer undergoing docetaxel chemotherapy, JGEE was found to be able to inactivate cytochrome *C*, enhance Bcl-2/Bax and Bcl-xL, and inhibit cleaved Caspase-3. It can significantly reduce myocardial injury in mice, prevent myocardial cell apoptosis, alleviate chemotherapy-induced cardiac toxicity, and enhance chemotherapy drugs to exert better anticancer effects. In addition, the active ingredient PD in Jiegeng can downregulate the expression of Bax and Caspase-3 in rats with acute myocardial infarction, upregulate the expression of Bcl-2, inhibit the AT1-CARP signaling pathway, reduce myocardial cell apoptosis, and improve coronary artery blood supply, thus playing a protective role in the heart (Meng, Liu, Huang, Yang, & Yang, 2021). In summary, Jiegeng has a cardioprotective activity and can be used as an adjuvant treatment for heart disease.

4.8. Other activities

Besides the above-mentioned pharmacological activities, *P. grandiflorum* also can prevent and treat Alzheimer's disease, improve memory, relieve depression, prevent pregnancy, treat osteoporosis, remove scars, and promote wound healing.

The aggregation of pathological factor amyloid-beta (Aβ) peptide can trigger Alzheimer's disease. Through the maze experiment on 5XFAD mice, it was found that mice given JGAE significantly improved cognitive impairment, and significantly reduced Aβ accumulation, neurodegeneration, oxidative stress, and neuroinflammation (Nam et al., 2021). Another study showed that PD activated AMPK to enhance its antioxidant capacity and improve memory function in Alzheimer's disease mice by inhibiting oxidative stress (Zhang, Du, et al., 2023). PD can also significantly stimulate neuroinflammation by stimulating the phosphorylation of the ERK1/2 signaling pathway, promoting the formation of hippocampal synapses, and playing an active role in improving memory (Kim et al., 2017). Furthermore, the extract from *P. grandiflorum* leaves can significantly reduce the TNF-α and IL-6 levels, increase the SOD activity, and improve the conditions of anhedonia and loss of appetite in depression model mice, which also proves that the antidepressant effect is related to antioxidant and anti-inflammatory activities (Wang et al., 2019). After treatment with PD (0.000 10 mol/L or 0.000 20 mol/L), the integrity of the human sperm membrane was assessed by evaluating hypo-osmotic swel-

ling (HOS) and examinations using transmission electron microscopy (TEM) and scanning electron microscopy (SEM). It was found that PD can cause damage to highly active human sperm, and the 0.2 μmol/L PD solution killed almost all the sperm. This study also found that even in the uterine environment, PD can effectively prevent sperm from reaching the egg or fertilizing the egg. These results indicate that PD reduces fertility to zero and exerts a contraceptive effect (Lu, Yang, Jia, & Zhao, 2013). Moreover, PD has been shown to hinder osteoclast differentiation by inhibiting the activation of NF-κB, ERK, and p38 mitogen-activated protein kinase (p38 MAPK). This contributes to its therapeutic effects on osteoporosis (Choi et al., 2017). It also inhibits the proliferation and migration of hypertrophic scar tissues by suppressing fibrosis-related molecules and inducing apoptosis via caspase-dependent pathways (Yu et al., 2022). In addition, the flavonoid component of Jiegeng, iridoid glycoside, can reduce the expression levels of TNF-α and IL-6 proteins, alleviate inflammation, promote blood vessel formation, and facilitate wound healing in rats with skin burns (Wang et al., 2022b).

5. Application

With the improvement in living standards and increase in public health awareness, the exploitation of *P. grandiflorum* is receiving increasing attention. Jiegeng ventilates the lungs, improves the pharynx, eliminates phlegm, and discharges pus. It is used to treat coughs and phlegm, chest tightness, sore throats, and lung abscesses (Chinese Pharmacopoeia Commission, 2020). Jiegeng Tang, a traditional Chinese medicinal compound, is mainly used to treat lung diseases, especially sore throat and chest stuffiness, with a high rate of use in pediatrics (Shan et al., 2012). Jiegeng is also the main drug in many Chinese patent medicines, including Platycodon Donghuanhua Tablets, Codeine Platycodon Tablets, Compound Jiegeng Cough Tablets, and Ke Chuan Ning. A total of 1 826 Chinese prescriptions and 685 Chinese patent medicines containing Jiegeng were searched on the YaoZH website (https://db.yaozh.com).

Jiegeng has been used as a medicinal agent for several years. This Jiegeng product has a long history of use in royal court literature and as a dietary remedy by doctors during the Qing Dynasty (Wang, Bai, & Li, 2023). Besides being rich in chemical components that can relieve cough and sputum, as well as have antitumor, anti-inflammatory, and other pharmacological effects, Jiegeng also contains certain nutrients. Compared with rhizome herbs, Jiegeng contains more proteins, among which the lysine content is higher than that in general cereals (Zhang et al., 2019). In 2021, *P. grandiflorum* will be classified as a national agricultural geographical indicator product in the vegetable category. Using Jiegeng to produce low-salt healthy pickles can better preserve the nutritional components of Jiegeng while maintaining the sensory quality of the pickles. The taste of this pickle is superior to that of regular pickles, and it contains higher levels of nutritional components, such as saponins, polysaccharides, and amino acids, which provide numerous health benefits (Li & Zhou, 2008). Sausages have high salt and fat levels, which can lead to health problems such as obesity, hypertension, and hyperlipidemia if consumed over the long term. To maintain the quality of emulsified sausages while reducing fat content, you can replace 5% fat with 2% Jiegeng powder. This will help increase the nutritional value and flavor of the sausages (Zhu, Zhang, & Yu, 2019). Jiegeng is an excellent material for developing healthy beverages. The Jiegeng-clarified beverage could prevent asthma and antioxidation. The specific processes were as follows: raw material processing, synergistic ultrasound and microwave extraction and separation, enzymatic hydrolysis, mixing, bottling, and sterilization (Wang et al., 2014). Besides the above-mentioned Jiegeng pickles, Jiegeng sausages and various Jiegeng-related foods have been developed, such as Jiegeng rice vinegar, Jiegeng wine, and other health foods, and can be eaten with chicken, pork, pigeon meat, and other stews as medicinal foods with rich taste and health benefits. The edible application of *P. grandiflorum* provides more choices for modern medicine and healthcare (Fig. 8).

With the increasing research on *P. grandiflorum*, various applications have been developed not only for drug development but also for food, health products, and daily necessities. For example, Jiegeng is used in various food applications, such as pickles, sausages, rice vinegar, wine and beverages. The traditional medicinal application is Jiegeng Tang. In modern times, a variety of drugs have been developed, such as Jiegeng Donghua Tablets and Codeine Jiegeng Tablets. In addition to Chuanbei Pipa Syrup and Jiegeng tea bags, Jiegeng and its extracts have been developed in various dosage forms as raw materials for health products. Besides being used as medicine, food, and health products, *P. grandiflorum* is also utilized in various industries such as whitening and skincare products, toothpaste, chicken feed, and biocides.

With the continuous improvement of people's living standards and quality of life, the concept of "preventing diseases before they occur" has become deeply ingrained in people's minds. The discussion of health based on the concepts of medical and food homology has received widespread attention. In 2002, the Jiegeng of China was included in the first list of medicinal and food homologs. According to the National Special Food Information Query Platform of the State Administration for Market Regulation, a total of 67 products are approved as health food ingredients using Jiegeng and its extracts. These products have been identified to have nine specific health functions, including soothing the throat, lowering blood, sugar and blood lipid levels, immune regulation, relieving physical fatigue, improving sleep quality, promoting bowel movements, treating sores, and enhancing hypoxic tolerance. A total of 92.5% of the products have only one specific health function, whereas 7.5% of the products have two or more health functions. Among these, throat soothing accounted for the largest proportion, there were 51 types, at 76.1% (Wang, Bai, & Li, 2023). According to the announcement issued by the State Administration for Market Regulation of China on the "Product Dosage Forms and Technical Requirements for Health Food Filing", a total of 67 types of Jiegeng health food can be classified into five dosage forms, which include oral liquid, tablets, capsules, granules, and gel candies. In addition, tea bags for healthy wine and green plums are available for oral consumption. As a representative medicinal and food homologous herb, Jiegeng should fully utilize its existing resources and develop new products using advanced technologies. This will contribute to the development of modern medicine and the health-food industry.

Besides being used as medicine, food, and healthcare products, *P. grandiflorum* products on the market are also used in many fields, such as skin beauty, cleaning, agriculture, and forestry. For the first time, the separation and purification of the Jiegeng whitening active extract were achieved, which contained 45 chemical components, including PD, luteolin, platycoside E, platycodin D3, and baicalin. These ingredients play a synergistic role in whitening the skin through the anti-inflammatory and antioxidant effects of Jiegeng and can be used to develop healthy and effective skincare products and cosmetics (Ma et al., 2021). The Jiegeng methanol extract was converted by pectinase to obtain 3-*O*-β-*D*-glucopyranosyl platycosides can synergically exert anti-inflammatory, antioxidant, and whitening effects, and is a good raw material for making whitening cosmetics (Ju et al., 2021). The Japanese Kao Cosmetics Company has launched whitening essences, whitening essence milk, and other whitening products containing *P. grandiflorum*-whitening active ingredients. A skin-

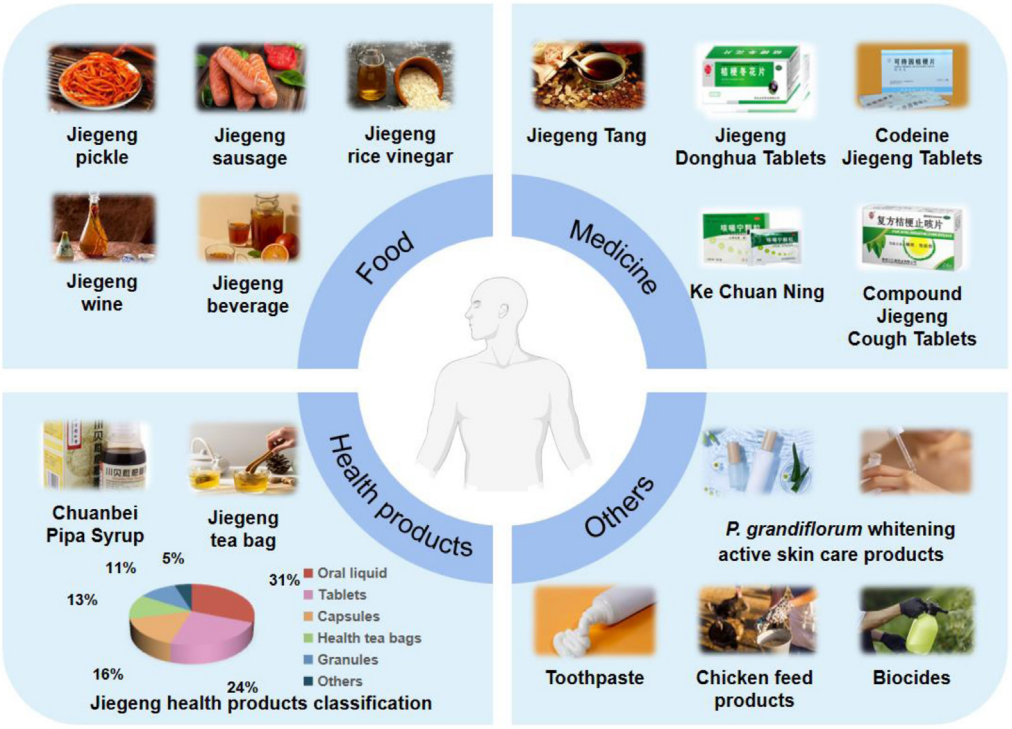


Fig. 8. Applications of *P. grandiflorum*.

lightening care product and pharmaceutical composition with PD were developed by Biospectrum Korea and have superior efficacy in inhibiting melanin production and preventing pigmentation (Zhao et al., 2023). Commercially available TCM toothpaste containing Jiegeng extracts has the characteristics of low price and good effectiveness in stain removal and cavity prevention. In agriculture and forestry, chicken feed products rich in JGS can promote chicken gut development and improve animal health. Biocides and biosurfactants made from plant extracts containing JGS are added to crops, which are beneficial to the growth of crops and are not harmful (Zhang, Chai, Hou, Zhao, & Meng, 2022).

In recent years, these applications have transformed into numerous patent achievements. According to Baiten's database, when using "*P. grandiflorum*" as a search keyword, a total of 18 272 patents were retrieved, with 18 187 patents originating from China. Additionally, 85 patents were obtained from the World Intellectual Property Organization. Fig. 9 shows the annual number of *P. grandiflorum* patents applications over the past 20 years. The number of *P. grandiflorum* patent applications reached its peak in 2015, with 2 327 patents, which was the highest in history. Through technical classification and statistical analysis, we found that many patents focused on human life essentials. Specifically, there were 17 044 patents, which accounted for 93.59% of all patents. Among them, the number of patents for pharmaceuticals and food was relatively large (accounting for 79.93% and 17.03% of the total patents). There are 14 605, 3 112, and 112 patents related to pharmaceuticals, food, and cosmetics, respectively. With the improvement in living standards and the increase in public health awareness, *P. grandiflorum* development is receiving increasing attention. Based on the identification of its pharmaco-

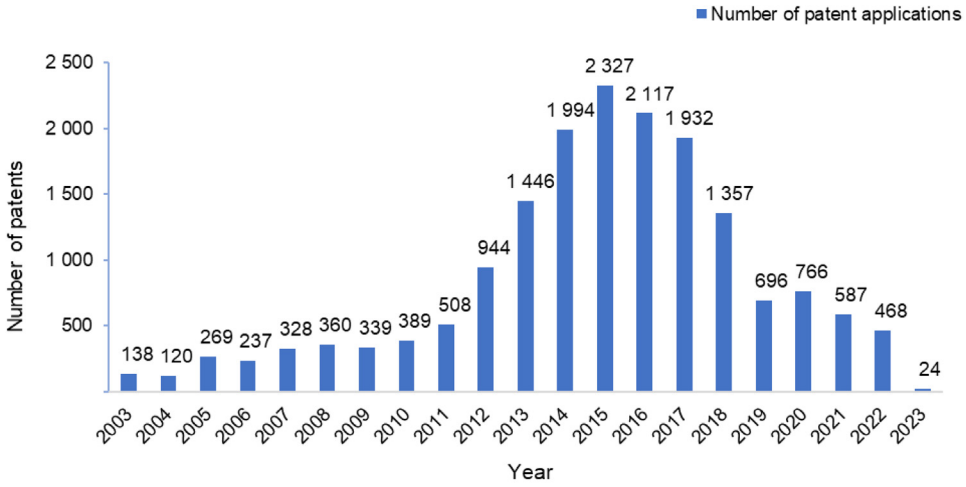


Fig. 9. Annual patent applications quantity of *P. grandiflorum* in past 20 years.

logical activity, there will be greater space for the development of *P. grandiflorum* resources.

The figure depicts a bar chart illustrating the number of patent applications for *P. grandiflorum* from 2003 to 2023. The highest point was reached in 2015, with a total of 2 327 applications filed.

6. Conclusion and prospect

Jiegeng, the roots of *P. grandiflorum* have a history of several thousand years as a TCM used to relieve coughs and promote lung function. *P. grandiflorum* contains functional factors, such as saponins, flavonoids, polysaccharides, phenolic acids, and polyacetylenes, as well as nutrients, such as fatty acids, amino acids, and vitamins. Modern pharmacological studies have confirmed that *P. grandiflorum* has various pharmacological activities, including antitussive, expectorant, antitumor activity, anti-inflammation, antioxidation, anti-obesity, and protective effects on the liver and heart.

In terms of food development, besides the long history of Jiegeng pickles, people have also developed Jiegeng beverages, sausages, and dried fruits. Furthermore, Jiegeng tablets, oral solutions, wines, and other health foods have been developed. In the field of cosmetics, *P. grandiflorum* can synergistically exert whitening effects through its antioxidant and anti-inflammatory properties, and various mild, stable, and non-toxic traditional Chinese medicinal cosmetics have been developed. In addition, it also has ornamental value with long flowering period and color diversity, and is suitable for arranging flower beds and flower arrangements in today's urbanization construction, which is a very promising development.

As a medicinal plant with high comprehensive economic value that encompasses medicinal, food, and ornamental uses, *P. grandiflorum* should not only focus on researching its roots (the traditional medicinal part of *P. grandiflorum*), but also on aboveground parts such as leaves, flowers, and seeds. This includes studying the chemical components and exploring their pharmacological activities. Furthermore, the extraction process should be optimized to prevent active ingredient loss, thereby providing a theoretical foundation for the comprehensive development and precise utilization of *P. grandiflorum*. In addition, it is important to pay attention to the safety and quality of medicinal materials. Therefore, monitoring the heavy metal content is necessary to ensure *P. grandiflorum* safety. Moreover, by focusing on the correlation between the components and efficacy, it is important to comprehensively control the quality of Jiegeng medicinal materials. This can be achieved by establishing a quality evaluation system that aligns with the characteristics of TCM, which involves "multiple components, targets, and effects". In addition, a quality evaluation method based on the Q-marker concept should be implemented. This study provides scientific references for quality control and the future development of *P. grandiflorum*.

This paper summarizes the history of Jiegeng (the roots of *P. grandiflorum*) as both medicine and food, and outlines the domestic and international applications of *P. grandiflorum*. It focuses on the chemical components, pharmacological effects, and related product development of *P. grandiflorum*. In addition, Jiegeng and its extract were classified as health food dosage forms, and their health effects were analyzed. Patent achievements related to *P. grandiflorum* were summarized and analyzed. It provides a reference for further studies on the pharmacological activity and clinical application of *P. grandiflorum* and lays a theoretical foundation for the development of related products.

In conclusion, with continuous in-depth research on the biological activity and clinical applications of *P. grandiflorum* as well as in the fields of medicine, food, health products, and cosmetics, *P. grandiflorum* will have greater utilization value and development space.

Declaration of Competing Interest

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

CRediT authorship contribution statement

Lanying Zhang: Conceptualization, Formal analysis, Writing – original draft, Visualization, Writing – review & editing. **Xinrui Wang:** Conceptualization, Writing – review & editing. **Jingze Zhang:** Conceptualization, Writing – review & editing. **Dailin Liu:** Conceptualization, Writing – review & editing. **Gang Bai:** Conceptualization, Writing – review & editing.

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