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Pyracantha fortuneana (Maxim.) Li: A comprehensive review of its phytochemistry, pharmacological properties, and product development

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Pyracantha fortuneana (Maxim.) Li has been used as a herbal medicine in China in its long history. Since ancient times, the fruits of *P. fortuneana* has been considered a functional food to improve various diseases. Many bioactive substances, including proanthocyanidins, phenols, polysaccharides, and dietary fibers, have been isolated and identified from the *P. fortuneana*, which possess diverse biological properties both *in vitro* and *in vivo*. Although the researches on the *P. fortuneana* have achieved extensive progress, the systematic study of its biological activities is still relatively lacking. In addition, accumulating researches focus on the landscape value of the *P. fortuneana* and the development of its by-products. The by-products of *P. fortuneana*, which show good development potentials in the field of agricultural production and environmental protection, are important for improving the economic value of *P. fortuneana* and its significance. After extensive reviewing and analyzing the existing published articles, books, and patents, this study aims to a systematic and summarized research trends of *P. fortuneana* and its phytochemical compositions, nutritional values, pharmacological effects and health benefits of its extracts/monomers, which would be beneficial for the future development of this medicinal plant as functional food or drugs.

KEYWORDS

Pyracantha fortuneana (Maxim.) Li, phytochemistry, botany, pharmacological properties, product development

Introduction

Pyracantha fortuneana (Maxim.) Li is an evergreen wild shrub and fruit tree of the genus *Pyracantha* in the *Rosaceae* apple subfamily, distributed from eastern Asia to southern Europe. So far, 10 species of *Pyracantha* have been reported in the world, while seven species have been found in China, and mainly produced in the southeastern and southwestern provinces of China (Jiang et al., 2007; Nai et al., 2020).

In the recent years, accumulating scientific research related to *P. fortuneana* has carried out a lot of researches on the nutritional components, efficacy, and processing application of *P. fortuneana*, and found that *P. fortuneana* contains many biological active substances, including proanthocyanidins, phenols, natural pigments, polysaccharides, dietary fiber, etc. Furthermore, the previous literatures also revealed that *P. fortuneana* and its bioactive substances possess various pharmacological activities, including anti-tumor effects, immune regulation effects, antioxidative effects, blood lipid-lowering effects, regulating effects on intestinal flora, and protecting effects on kidney (Chen et al., 2011). In addition, the fruits of *P. fortuneana* can be used as nutritional supplement. It is reported that the moisture content of fresh fruits of *P. fortuneana* is above 60%, which is close to the moisture content of most fruits on the market (>65%), the ash content is 1.83%, the amino acid content is 2.80 g/kg. The crude fat content of the fruits of *P. fortuneana* is 1.30%, higher than apples and macaques (Chen and Tan, 2021). Essential trace elements are required by man in amounts ranging from 50 µg to 18 mg per day. Acting as catalytic or structural components of larger molecules, they have specific functions and are indispensable for life (Mertz, 1981). In He's study, it has determined the trace elements contents in the fruits of *P. fortuneana* by ICP-MS, and found that 16 trace elements were detected, including Sc, Y, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, and Lu (He et al., 2018). What is more prevalent in the case is that the contents of trace elements in the leaves of *P. fortuneana* were higher than that in the fruits of *P. fortuneana* (592 vs. 104 µg/kg) (He et al., 2019). Compared with white radish, the presence of Cu in the fruits of *P. fortuneana* is 9 times and that of Zn is 3 times, Fe is 2 times, and Mn is 2 times (Huang, 2014). The metal elements in the fruits of *P. fortuneana* were determined by flame atomic absorption spectrometry, and the content of metal elements was Mg > Fe > Zn, while another experiment showed a different result of Fe > Mg > Zn (Chu et al., 2015; Gao Z. Y. et al., 2019). It is reported that the fruits of *P. fortuneana* contains 149.40 mg/g soluble sugar, 105.00 mg/g soluble protein, 0.32 mg/g Vitamin C (Vc), 3.34 µg/g anthocyanin, 11.88 mg/g polyphenol, 2.10 mg/g total flavonoid, and the peroxidase activity was 0.16 µg/min (Han and Zhang, 2019). Four species of *P. fortuneana* in Guizhou were analyzed by the anthrone colorimetric method, 2,6-dichlorophenol-indophenol titration method and phenolphthalein indicator method. The related results showed that the soluble sugar content in the fruits of *Pyracantha crenulata* variant was the highest (13.02%), and the results also showed that the Vc content and organic acid content in the fruits of *P. crenulata* were the highest (696.9 mg/kg and 0.84%) (Fu, 2014). The nutritional value of *P. fortuneana* leaves varies greatly in different seasons. The newly sprouted leaves in spring has the best nutritional value, with a crude protein content of 15.5%, the crude fat content of 3.5%, Ca content of 1.01%, total phosphorus content of 0.83%, and

carotene content of 1,025 µg/kg (Zhou et al., 2017). It has many functions contributing to nutritional and healthy food, medicine, cosmetics, daily necessities, bonsai cultivation, and ecology, etc., and its comprehensive utilization value is high and has a broad market value (Huang and Fu, 2014).

This study summarized the research progress of the functional components of *P. fortuneana* and their extraction process, pharmacological effects, industrial development, and utilization discovered in the recent years, which would provide research basis and reference as an important raw material for many functional foods and medicines that can be prepared from this plant.

Traditional uses

The edible and medicinal properties of *P. fortuneana* have long been proven by practice in the producing areas. The Yi people in Liangshan have a tradition of using the fruits of *P. fortuneana* as a medicine and food (Wang et al., 2020). The fruit of *P. fortuneana*, first recorded in "Southern Yunnan Materia Medica," has been used in folk medicine with various medicinal functions, such as "invigorating the spleen and eliminating accumulation, promoting body fluid and quenching thirst, clearing heat and detoxifying, promoting blood circulation, and stopping bleeding" (Zeng et al., 2016), and it can be used to treat lumps in the chest, food accumulation, metrorrhagia, postpartum blood stasis, and other symptoms, but also eliminates insects and boost eyesight (Hou et al., 2002). Besides, the root of *P. fortuneana* can also be used as medicine in folk medicine with the functions of "upward diarrhea, hemostasis, dispersing stasis, and eliminating accumulation." It can be also used for hemorrhoids bleeding, red eyes, swelling and pain, wind-fire toothache, bruises, and other symptoms (Luo et al., 2014). In some areas of China, the leaves of *P. fortuneana* can be used as tea, which can "clear heat and detoxify, promote body fluid and quench thirst, and relieve diarrhea" (Wang and Deng, 1988).

Botany

The *P. fortuneana* is an evergreen shrub, up to 3-m tall; lateral branches are short thorn-like at the apex; young branches are covered with rust-colored pubescent hairs; old branches are dark brown and glabrous; and buds are small and covered with pubescent hairs (Tang and Liu, 2002). Leaf-blade is obovate or obovate-oblong, 1.5–6 cm long, 0.5–2 cm wide, apex rounded or slightly concave, sometimes with short cusps, base cuneate, extending down to petiole, margin with blunt serrations, teeth of the tip is curved inward, nearly the base is entire, and both surfaces are glabrous; the petiole is short, glabrous, or pubescent when young (Su, 2019). Flowers are integrated into compound corymbs, 3–4 cm in diameter pedicels and common



FIGURE 1
Pyracantha fortuneana (Maxim.) Li.

pedicels nearly glabrous, pedicels about 1-cm long; flowers about 1 cm in diameter; calyx tube campanulate, glabrous; sepals triangular-ovate, apex obtuse; petals are white, nearly round, about 4-mm long, and 3-mm wide; stamens are 20 in number, filaments 3–4-mm long, anther is in yellow color; styles 5 in number and free, as long as stamens, densely white pubescent on the upper part of the ovary. The fruit is nearly spherical, about 5 mm in diameter, orange-red or dark red. The flowering period is during March–May, and the fruiting period is during August–November (Editorial Committee of Flora of China and Chinese Academy of Sciences,

1973). The flowers and fruits of *P. fortuneana* are shown in Figure 1.

The mature fruits of *P. fortuneana* has a strong aroma, sweet and sour, and a unique flavor. It can be eaten fresh, or it can be dried and ground to replace grain. It is often called “military grain” and “life-saving grain.” Because of its dense branches and leaves, orange or bright red cones are densely packed and covered with branches. Distributed in groups by the hillside ditch, it is also known as “red son” and “torch fruit” (Li et al., 2012; Gao, 2020). The general geographical distribution of *P. fortuneana* shows in Figure 2.



FIGURE 2
General geographical distribution of *P. fortuneana* (Maxim.) Li in the world [Color figure can be viewed at [wileyonlinelibrary.com](https://www.wileyonlinelibrary.com)].

Phytochemistry

The recent researches show that *P. fortuneana* is rich in nutrients, mainly including flavonoids, terpenes, phenolic acids, glycosides, carbohydrates, and steroids (Sharifi-Rad et al., 2020). Until now, more than 220 compounds have been isolated and identified from this plant. In this review, the constituents in this plant were comprehensively reported, including phenolic acids, flavonoids, anthocyanins, carbohydrates, terpenes, steroids, alkaloids, alkanes, esters, and phenylpropanoids. In this section, the identified constituents of *P. fortuneana* are listed in the tables and the corresponding structures are also comprehensively presented (Tables 1–4, Figures 3–6).

Phenols

Phenolic compounds are the secondary metabolites synthesized by plants, they are present in everyday foods such as fruits and vegetables, contributing to the unique sensory and organoleptic properties; for instance, color, astringency, and taste of the fruits and vegetables. Phenolic compounds are associated with atherosclerosis, cardiovascular disease, antioxidants, cancer prevention, and neurodegenerative diseases (Chhikara et al., 2019; Laganà et al., 2020). Dai et al. isolated a series of biphenyl glycosides and acylphloroglucinol glycosides from the fruits of *P. fortuneana*, of which seven glycosides had mild tyrosinase (TYR) inhibitory activity (Dai et al., 2006, 2008, 2009). The inhibitory activity of biphenyl glycosides possibly arose from the chelating to copper ion in the

active site of the TYR (Yuan et al., 2015b). It is reported that the fruits of *P. fortuneana* also contain 9-hydroxyeribofuran (12), 5,7-dihydroxychromone-7- β -D-glucoside (13), arbutin (14), cimidahurinine (15), eugenol (16), Vanillin (17), and 3-hydroxyphloretin 2'-O-glucoside (18) (Zhu et al., 2013; Ge et al., 2014; Shim et al., 2020; Sharifi-Rad et al., 2021). Among them, arbutin treatment fends off glucocorticoid-induced osteoporosis, partly through promoting differentiation and mineralization of osteoblasts by autophagy activation (Zhang Y. et al., 2021). Eugenol inhibited the complex I activity of the mitochondrial respiratory chain in the oxidative phosphorylation pathway by binding to nicotinamide adenine dinucleotide dehydrogenase chain 2 and resulted in the death of mites (Shang et al., 2021). Vanillin enhanced liver regeneration in thioacetamide-induced liver damage model, targeting growth factors of hepatocyte growth factor (HGF) and vascular endothelial growth factor (VEGF), and cellular proliferation marker of cyclin D1 (Ghanim et al., 2021).

It is reported that the fruits of *P. fortuneana* contain both hydroxybenzoic and hydroxycinnamic acid derivatives, which are the two major categories of phenolic acids in plants. These phenolic acids are present in free or conjugated form, commonly as simple esters with quinic acid or glucose (Mattila and Kumpulainen, 2002; Russell et al., 2009). Among these hydroxybenzoic acids, gallic acid (20), 4-hydroxybenzoic acid (21), 3-O-methylgallic acid (23), 3-hydroxybenzoic acid (27), 2,3-dihydroxybenzoic acid (29), veratric acid (39), and their glycoside derivatives have been reported in the fruits of *P. fortuneana*. Hydroxycinnamic acids include *m*-coumaric acid (24), *p*-coumaric acid (25), caffeic acid (31), ferulic acid (33),

TABLE 1 The chemical constituents of phenols.

No.	Compound name	Formula	Part	References
Phenols				
1	3,3'-Dihydroxy-5'-methoxy-(1,1'-biphenyl)-4-O-β-D-glucoside	C ₁₉ H ₂₂ O ₉	Fruit	Dai et al., 2006
2	3,4'-Dihydroxy-3',5'-dimethoxy-(1,1'-biphenyl)-4-O-β-D-glucoside	C ₂₀ H ₂₄ O ₁₀	Fruit	Dai et al., 2006
3	4'-Hydroxy-2,3',5'-trimethoxy-(1,1'-biphenyl)-2'-O-β-D-glucoside	C ₂₁ H ₂₆ O ₁₀	Fruit	Dai et al., 2006
4	4'-Hydroxy-3',5'-dimethoxy-(1,1'-biphenyl)-2-O-β-D-glucoside	C ₂₀ H ₂₄ O ₉	Fruit	Dai et al., 2006
5	2,4'-Dihydr Isoorientin oxy-3',5'-dimethoxy-(1,1'-biphenyl)-3-O-β-D-glucoside	C ₂₀ H ₂₄ O ₁₀	Fruit	Dai et al., 2006
6	2,4,6-Trihydroxy-acetophenone-6-O-α-L-rhamnopyranosyl-(1→6)-b-D-glucopyranoside	C ₂₀ H ₂₈ O ₁₃	Fruit	Dai et al., 2008
7	2,4,6-Trihydroxy-acetophenone-6-O-β-D-glucopyranoside	C ₁₄ H ₁₈ O ₉	Fruit	Dai et al., 2008
8	2,4,6-Trihydroxy-acetophenone-4-O-β-D-glucopyranoside	C ₁₄ H ₁₈ O ₉	Fruit	Dai et al., 2008
9	2,4,6-Trihydroxy-benzophenone-6-O-α-L-rhamno-pyranosyl-(1→6)-b-D-glucopyranoside	C ₂₅ H ₃₀ O ₁₃	Fruit	Dai et al., 2008
10	2,4,6-Trihydroxy-benzophenone-6-O-β-D-apiofuranosyl-(1→6)-b-D-glucopyranoside	C ₂₄ H ₂₈ O ₁₃	Fruit	Dai et al., 2008
11	Garcimangosone D	C ₁₉ H ₂₀ O ₉	Fruit	Dai et al., 2008
12	9-Hydroxyeribofuran	C ₁₄ H ₁₂ O ₅	Leaf	Shim et al., 2020
13	5,7-Dihydroxychromone-7-β-D-glucoside	C ₁₅ H ₁₆ O ₈	Leaf	Shim et al., 2020
14	Arbutin	C ₁₂ H ₁₆ O ₇	Leaf	Shim et al., 2020
15	Cimidahurinine	C ₁₄ H ₂₀ O ₈	Leaf	Shim et al., 2020
16	Eugenol	C ₁₀ H ₁₂ O ₂	Flower	Ge et al., 2014
17	Vanillin	C ₈ H ₈ O ₃	Leaf	Zhu et al., 2013
18	3-Hydroxyphloretin 2'-O-glucoside	C ₂₁ H ₂₄ O ₁₁	Fruit	Sharifi-Rad et al., 2021
Phenolic acids				
19	Chlorogenic acid	C ₁₆ H ₁₈ O ₉	Fruit	Belwal et al., 2019
20	Gallic acid	C ₇ H ₆ O ₅	Fruit, leaf	Belwal et al., 2019; Sharifi-Rad et al., 2021
21	4-Hydroxybenzoic acid	C ₇ H ₆ O ₃	Fruit	Belwal et al., 2019
22	4-Hydroxybenzoic acid 4-O-glucoside	C ₁₃ H ₁₆ O ₈	Leaf	Sharifi-Rad et al., 2021
23	3-O-Methylgallic acid	C ₈ H ₈ O ₅	Leaf	Sharifi-Rad et al., 2021
24	m-Coumaric acid	C ₉ H ₈ O ₃	Fruit	Belwal et al., 2019
25	p-Coumaric acid	C ₉ H ₈ O ₃	Fruit	Belwal et al., 2019
26	Ellagic acid	C ₁₄ H ₆ O ₈	Fruit	Belwal et al., 2019
27	3-Hydroxybenzoic acid	C ₇ H ₆ O ₃	Fruit	Belwal et al., 2019; Sharifi-Rad et al., 2021
28	2-Hydroxybenzoic acid	C ₇ H ₆ O ₃	Leaf	Sharifi-Rad et al., 2021
29	2,3-Dihydroxybenzoic acid	C ₇ H ₆ O ₄	Leaf	Sharifi-Rad et al., 2021
30	1,5-Dicaffeoylquinic acid	C ₂₅ H ₂₄ O ₁₂	Leaf	Sharifi-Rad et al., 2021
31	Caffeic acid	C ₉ H ₈ O ₄	Fruit	Belwal et al., 2019; Sharifi-Rad et al., 2021
32	Caffeic acid 3-O-glucuronide	C ₁₅ H ₁₆ O ₁₀	Leaf	Sharifi-Rad et al., 2021
33	Ferulic acid	C ₁₀ H ₁₀ O ₄	Fruit, leaf	Belwal et al., 2019; Sharifi-Rad et al., 2021
34	Ferulic acid 4-O-glucuronide	C ₁₆ H ₁₈ O ₁₀	Leaf	Sharifi-Rad et al., 2021
35	3-p-Coumaroylquinic acid	C ₁₆ H ₁₈ O ₈	Leaf	Sharifi-Rad et al., 2021
36	Ursolic acid	C ₃₀ H ₄₈ O ₃	Fruit	Xu et al., 2016; Shim et al., 2020
37	Oleanolic acid	C ₃₀ H ₄₈ O ₃	Fruit	Xu et al., 2016
38	2-Oxopomolic acid	C ₃₀ H ₄₆ O ₅	Leaf	Shim et al., 2020
39	Veratric acid	C ₉ H ₁₀ O ₄	Fruit	Wang et al., 2019
40	Sinapoylglucose	C ₁₇ H ₂₂ O ₁₀	Fruit	Wang et al., 2019
41	5-p-Coumaroylquinic acid	C ₁₆ H ₁₈ O ₈	Fruit	Wang et al., 2019
42	Pomolic acid	C ₃₀ H ₄₈ O ₄	Leaf	Shim et al., 2020

(Continued)

TABLE 1 Continued

No.	Compound name	Formula	Part	References
43	<i>p</i> -Hydroxybenzoic acid β -D-glucosyl ester	C ₁₃ H ₁₆ O ₈	Leaf	Shim et al., 2020
44	Pyracenic acid	C ₃₉ H ₅₄ O ₆	Bark	Otsuka et al., 1981
Proanthocyanidins				
45	Cyanin	C ₂₇ H ₃₁ O ₁₆ ⁺	Fruit	Belwal et al., 2019
46	Delphinidin	C ₁₅ H ₁₁ ClO ₇	Fruit	Belwal et al., 2019
47	(+)-Catechin	C ₁₅ H ₁₄ O ₆	Fruit, leaf	Zhao et al., 2015; Belwal et al., 2019; Shim et al., 2020; Sharifi-Rad et al., 2021
48	Catechin-glucosides	C ₂₁ H ₂₄ O ₁₁	Fruit	Zhao et al., 2015
49	Gallocatechin	C ₁₅ H ₁₄ O ₇	Fruit, leaf	Zhao et al., 2015; Sharifi-Rad et al., 2021
50	Epigallocatechin	C ₁₅ H ₁₄ O ₇	Fruit	Zhao et al., 2015
51	(+)-Epicatechin	C ₁₅ H ₁₄ O ₆	Fruit	Zhao et al., 2015
52	Epicatechin-3-glucosides	C ₂₁ H ₂₄ O ₁₂	Fruit	Zhao et al., 2015

5-*p*-coumaroylquinic acid (41), and their glycoside derivatives. In addition, phenolic acids formed by the condensation of hydroxycinnamic acid and hydroxybenzoic acid have also been found, such as chlorogenic acid (19), 1,5-dicaffeoylquinic acid (30), and 3-*p*-coumaroylquinic acid (35) (Otsuka et al., 1981; Gan et al., 2012; Xu et al., 2016; Belwal et al., 2019; Wang et al., 2019; Sharifi-Rad et al., 2021). Chlorogenic acid attenuates dextran sulfate-induced ulcerative colitis in mice by reducing tissue inflammation and apoptosis (Gao W. et al., 2019). Ellagic acid protects against 3-nitropropionic acid induced mitochondrial dysfunction and oxide-nitrosative stress in the brain (Sharma et al., 2021; Zhang Q. et al., 2021). Ferulic acid potentially improved hepatic fibrosis *via* inhibition of the TGF- β 1/Smad pathway *in vitro* and *in vivo* (Mu et al., 2018).

Proanthocyanidins are also important components of *P. fortuneana* polyphenols. Using the fruits of the wild *P. fortuneana* as material, proanthocyanidins were extracted with an ethanol solution, the yield could reach 93.446 mg/g (Yang et al., 2011). The highest yields of flavonoids and proanthocyanidins were 3.47 and 4.63%, and the yield of polyphenols was 3.86% by using the fruits of *P. fortuneana* from different origins and different harvest periods as raw materials (Li et al., 2008, 2020). Proanthocyanidins isolated from *P. fortuneana* were predominantly constituted of procyanidin with A-type and B-type linkages, including (+)-catechin (47), (+)-epicatechin (51), gallocatechin (49), and epigallocatechin (50). Besides, *P. fortuneana* also contains proanthocyanidins glycosides such as catechin-glucosides (48) and epicatechin-3-glucosides (52) (Zhao et al., 2015; Wei et al., 2017). The content of polyphenols in unripe fruits is high, and as the fruit matures, the phenolic substances are oxidized and the level of anthocyanin increases; for example, cyanin (45) and delphinidin (46) (Wei et al., 2017; Peng et al., 2019). The stability of proanthocyanidins in *P. fortuneana* during processing and storage was investigated. The processing and

storage temperature was lower than 80°C, and the stability of proanthocyanidins was good in the pH value ranging from 3 to 7; V_C, sodium citrate and sodium bisulfite were helpful to maintain the stability of proanthocyanidins; Cu²⁺ is not conducive to its stability, and Fe³⁺ has an obvious destructive effect; natural light is not conducive to the stability of proanthocyanidins, and ultraviolet light is very destructive (Liu et al., 2015). The chemical constituents of phenols and their corresponding structures are depicted in Table 1 and Figure 3.

Flavonoids

Flavonoids, commonly found in plants, are a class of polyphenolic compounds with the basic structural unit of 2-phenylchromone, and flavonoids have attracted much attention due to their wide range of biological applications (Wen et al., 2021). Modern studies have shown that flavonoids have pharmacological effects such as the treatment of diabetic retinopathy, anti-tumor, and hypolipidemic effects (Luo et al., 2021; Xuan et al., 2021; Xu et al., 2021). To date, more than 30 flavonoids have been isolated from the *P. fortuneana*. The flavonoid profiles of *P. fortuneana* at different ages showed obviously differences in aerial and hypogeal parts. In the vegetative phase, there are flavonoids (flavanones, flavones, and flavonols) only in the aerial parts and they appear gradually during the plant life (Fico et al., 2000).

The flavonoids reported in *P. fortuneana* include quercetin (53), apigenin (54), kaempferol (55), chrysin (57), hyperoside (59), vitexin (68), naringenin (71), pyracanthoside (75), eriodictyol (76), and hexaacetylpyracanthoside (87) in the leaves; the 5,7,2',5'-tetrahydroxyfavanone (60), myricetin (62), isoorientin (69), dihydrokaempferol (72), dihydroquercetin (74), sakuranetin (77), pinocembrin (78), sakuranin (80), and

TABLE 2 The chemical constituents of flavonoids.

No.	Compound name	Formula	Plant part	References
53	Quercetin	C ₁₅ H ₁₀ O ₇	Fruit, leaf	Fico et al., 2000; Gan et al., 2012
54	Apigenin	C ₁₅ H ₁₀ O ₅	Leaf	Fico et al., 2000
55	Kaempferol	C ₁₅ H ₁₀ O ₆	Leaf	Fico et al., 2000
56	Chrysin-5-glc	C ₂₁ H ₂₁ O ₉	Root	Fico et al., 2000
57	Chrysin	C ₁₅ H ₁₀ O ₄	Root	Fico et al., 2000
58	Norwogonin-5-glc	C ₂₁ H ₂₀ O ₁₀	Root	Fico et al., 2000
59	Hyperoside	C ₂₁ H ₂₀ O ₁₂	Fruit, leaf	Fico et al., 2000; He et al., 2011
60	5,7,2',5'-Tetrahydroxyfavanone	C ₁₅ H ₁₀ O ₆	Root	Fico et al., 2000
61	5,7,2,5'-Tetrahydroxyfavanone-7-glc	C ₂₁ H ₂₀ O ₁₁	Root	Fico et al., 2000
62	Myricetin	C ₁₅ H ₁₀ O ₈	Leaf	Fico et al., 2000
63	Myricetin 3-O-rhamnoside	C ₂₁ H ₂₀ O ₁₂	Leaf	Sharifi-Rad et al., 2021
64	Myricetin 3-O-galactoside	C ₂₁ H ₂₀ O ₁₃	Leaf	Sharifi-Rad et al., 2021
65	Apigenin 6-C-glucoside	C ₂₁ H ₂₀ O ₁₀	Leaf	Sharifi-Rad et al., 2021
66	7,4'-Dihydroxyflavone	C ₁₅ H ₁₀ O ₄	Leaf	Sharifi-Rad et al., 2021
67	Kaempferol 3,7-O-diglucoside	C ₂₇ H ₃₀ O ₁₆	Leaf	Sharifi-Rad et al., 2021
68	Vitexin	C ₂₁ H ₂₀ O ₁₀	Leaf	Fico et al., 2000
69	Isoorientin	C ₂₁ H ₂₀ O ₁₁	Leaf, fruit	Fico et al., 2000
70	Cosmosiin	C ₂₁ H ₂₀ O ₁₀	Leaf	Shim et al., 2020
71	Naringenin	C ₁₅ H ₁₂ O ₅	Leaf	Fico et al., 2000
72	Dihydrokaempferol	C ₁₅ H ₁₂ O ₆	Root	Fico et al., 2000
73	Naringenin-7-glucoside	C ₂₁ H ₂₂ O ₁₀	Leaf	Fico et al., 2000
74	Dihydroquercetin	C ₁₅ H ₁₂ O ₇	Root	Fico et al., 2000
75	Pyracanthoside	C ₂₁ H ₂₂ O ₁₁	Leaf, fruit	Fico et al., 2000
76	Eriodictyol	C ₁₅ H ₁₂ O ₆	Leaf	Fico et al., 2000
77	Sakuranetin	C ₁₆ H ₁₄ O ₅	Root	Fico et al., 2000
78	Pinocembrin	C ₁₅ H ₁₂ O ₄	Root	Fico et al., 2000
79	Pinostrobin-5-glc	C ₂₁ H ₂₂ O ₉	Root	Fico et al., 2000
80	Sakuranin	C ₂₂ H ₂₄ O ₁₀	Root	Fico et al., 2000
81	Dihydrowogonin	C ₁₆ H ₁₄ O ₅	Root	Fico et al., 2000
82	Dihydrowogonin-7-glc	C ₂₂ H ₂₄ O ₁₀	Root	Fico et al., 2000
83	2',4'-Dihydroxy-6'-methoxychalcone-4-glc	C ₂₂ H ₂₄ O ₁₀	Root	Fico et al., 2000
84	Phloridzin	C ₂₁ H ₂₄ O ₁₀	Fruit, leaf	Belwal et al., 2019; Sharifi-Rad et al., 2021
85	Procyanidin B2	C ₃₀ H ₂₆ O ₁₂	Fruit, leaf	Xu et al., 2016; Sharifi-Rad et al., 2021
86	Rutin	C ₂₇ H ₃₀ O ₁₆	Fruit	He et al., 2011
87	Hexaacetylpyracanthoside	C ₃₃ H ₃₄ O ₁₇	Leaf	Fico et al., 2000
88	Myricetin 3-O-rutinoside	C ₂₇ H ₃₀ O ₁₇	Leaf	Sharifi-Rad et al., 2021
89	Vitexin-2"-rhamnoside	C ₂₇ H ₃₀ O ₁₄	Leaf	Fico et al., 2000

dihydrowogonin (81) in the roots (Fico et al., 2000). The 7,4'-dihydroxyflavone (66), cosmosiin (70), phloridzin (84), and their glycoside derivatives in the leaves of *P. fortuneana* also reported in small quantities (Table 2, Figure 4; He et al., 2011; Shim et al., 2020; Sharifi-Rad et al., 2021).

Quercetin can be used to treat diabetes, hyperlipidemia, and non-alcoholic fatty liver disease (Yi et al., 2021). The content of quercetin in different parts of *P. fortuneana* varies greatly. It was reported that no Quercetin was detected in

the root of *P. fortuneana*, while the content of quercetin in the fruit was 4 times that of the leaves (Gan et al., 2012). Apigenin could suppress neovascularization, and it has antiapoptotic and antioxidative effects in an oxygen-induced retinopathy mouse model, and can be considered as a promising agent for treating ocular neovascular diseases (Sarigul Sezenoz et al., 2021). Eriodictyol can produce antidepressant-like effects and ameliorate cognitive impairments induced by chronic stress (Zhang et al., 2020). Chrysin has also

TABLE 3 The chemical constituents of volatile constituents.

No.	Compound name	Formula	Plant part	References
90	Germacrene D	C ₁₅ H ₂₄	Flower, fruit	Wang et al., 2013; Ge et al., 2014
91	Isoledene	C ₁₅ H ₂₄	Flower	Ge et al., 2014
92	Isophorone	C ₉ H ₁₄ O	Flower	Ge et al., 2014
93	α-Cubebene	C ₁₅ H ₂₄	Flower, fruit, leaf	Wang et al., 2013; Zhu et al., 2013; Ge et al., 2014
94	Jasmone	C ₁₁ H ₁₆ O	Flower, leaf	Zhu et al., 2013; Ge et al., 2014
95	Cadinene	C ₁₅ H ₂₄	Flower	Ge et al., 2014
96	α-Terpineol	C ₁₀ H ₁₈ O	Flower, fruit, leaf	Wang et al., 2013; Zhu et al., 2013; Ge et al., 2014
97	β-Ionone	C ₁₃ H ₂₀ O	Flower, fruit, leaf	Wang et al., 2013; Zhu et al., 2013; Ge et al., 2014
98	Epizonarene	C ₁₅ H ₂₄	Fruit, leaf	Wang et al., 2013; Zhu et al., 2013
99	β-Eudesmol	C ₁₅ H ₂₆ O	Fruit, leaf	Wang et al., 2013; Zhu et al., 2013
100	β-Carotene	C ₄₀ H ₅₆	Fruit	Humbeck et al., 1989; Wang C. F. et al., 2016
101	trans-Squalene	C ₃₀ H ₅₀	Flower, leaf	Zhu et al., 2013; Ge et al., 2014
101	Isoterpinolene	C ₁₀ H ₁₆	Fruit	Wang et al., 2013
102	Menthol	C ₁₀ H ₂₀ O	Fruit	Wang et al., 2013
103	Bicyclosquiphellandrene	C ₁₅ H ₂₄	Fruit	Wang et al., 2013
104	Megastigmatrienone	C ₁₃ H ₁₈ O	Leaf	Zhu et al., 2013
105	α-Calacorene	C ₁₅ H ₂₀	Leaf	Zhu et al., 2013
106	α-Ionone	C ₁₃ H ₂₀ O	Leaf	Zhu et al., 2013
107	α-Muurolene	C ₁₅ H ₂₄	Leaf	Zhu et al., 2013
108	α-Pinene	C ₁₀ H ₁₆	Leaf	Zhu et al., 2013
109	α-Terpinene	C ₁₀ H ₁₆	Leaf	Zhu et al., 2013
110	β-Cubebene	C ₁₅ H ₂₄	Leaf	Zhu et al., 2013
111	Roseoside	C ₁₉ H ₃₀ O ₈	Fruit	Wang et al., 2019; Shim et al., 2020
112	1,2,3-Trimethylcyclohexane	C ₉ H ₁₈	Fruit	Wang C. F. et al., 2016
113	Ethylcyclohexane	C ₈ H ₁₆	Fruit	Wang C. F. et al., 2016
114	Cyclododecane	C ₁₂ H ₂₄	Flower	Ge et al., 2014
115	Abietane	C ₂₀ H ₃₆	Fruit	Xu et al., 2016
116	Octane	C ₈ H ₁₈	Fruit	Wang C. F. et al., 2016
117	n-Nonane	C ₉ H ₂₀	Fruit	Wang C. F. et al., 2016
118	Decane	C ₁₀ H ₂₂	Fruit	Wang C. F. et al., 2016
119	n-Pentadecane	C ₁₅ H ₃₂	Leaf	Zhu et al., 2013
120	Docosane	C ₂₂ H ₄₆	Flower, fruit, leaf	Wang et al., 2013; Zhu et al., 2013; Ge et al., 2014
121	Tricosane	C ₂₃ H ₄₈	Flower	Ge et al., 2014
122	Tetracosane	C ₂₄ H ₅₀	Flower, fruit	Wang et al., 2013; Ge et al., 2014
123	Pentacosane	C ₂₅ H ₅₂	Leaf	Zhu et al., 2013
124	Hexanal	C ₆ H ₁₂ O	Flower	Ge et al., 2014
125	Octanal	C ₈ H ₁₆ O	Flower	Ge et al., 2014
126	Decanal	C ₁₀ H ₂₀ O	Flower	Ge et al., 2014
127	Tetradecanal	C ₁₄ H ₂₈ O	Flower	Ge et al., 2014
128	Heptaldehyde	C ₇ H ₁₄ O	Flower	Ge et al., 2014
129	Nonanal	C ₉ H ₁₈ O	Flower, leaf	Zhu et al., 2013; Ge et al., 2014
130	Undecanal	C ₁₁ H ₂₂ O	Flower	Ge et al., 2014
131	Hexadecanal	C ₁₆ H ₃₂ O	Flower	Ge et al., 2014
132	Farnesol	C ₁₅ H ₂₆ O	Flower	Ge et al., 2014
133	Farnesyl acetone	C ₁₈ H ₃₀ O	Flower	Ge et al., 2014
134	Furfural	C ₅ H ₄ O ₂	Flower	Ge et al., 2014
135	5-Methyl furfural	C ₆ H ₆ O ₂	Fruit	Wang et al., 2013

(Continued)

TABLE 3 Continued

No.	Compound name	Formula	Plant part	References
136	Furfuryl alcohol	C ₅ H ₆ O ₂	Leaf	Zhu et al., 2013
137	3-Furaldehyde	C ₅ H ₄ O ₂	Fruit	Wang et al., 2013
138	Phenylacetaldehyde	C ₈ H ₈ O	Flower	Ge et al., 2014
139	2-Hexenal	C ₆ H ₁₀ O	Flower	Ge et al., 2014
140	Lycopene	C ₄₀ H ₅₆	Fruit	Humbeck et al., 1989
141	2-Acetylfuran	C ₆ H ₆ O ₂	Fruit	Wang et al., 2013
142	β-Damascenone	C ₁₃ H ₁₈ O	Flower, leaf	Zhu et al., 2013; Ge et al., 2014
143	Perhydrofarnesyl acetone	C ₁₈ H ₃₆ O	Flower	Ge et al., 2014
144	2-Heptadecanone	C ₁₇ H ₃₄ O	Flower	Ge et al., 2014
145	2-Pentadecanone	C ₁₅ H ₃₀ O	Fruit, leaf	Wang et al., 2013; Zhu et al., 2013
146	Benzyl alcohol	C ₇ H ₈ O	Leaf	Zhu et al., 2013
147	Phenethyl alcohol	C ₈ H ₁₀ O	Flower, leaf	Zhu et al., 2013; Ge et al., 2014
148	Isophytol	C ₂₀ H ₄₀ O	Leaf	Zhu et al., 2013
149	Leaf alcohol	C ₆ H ₁₂ O	Flower, leaf	Zhu et al., 2013; Ge et al., 2014
150	Linalool	C ₁₀ H ₁₈ O	Flower, leaf	Zhu et al., 2013; Ge et al., 2014
151	Geraniol	C ₁₀ H ₁₈ O	Flower, leaf	Zhu et al., 2013; Ge et al., 2014
152	trans-Nerolidol	C ₁₅ H ₂₆ O	Flower	Ge et al., 2014
153	Ethylene brassylate	C ₁₅ H ₂₆ O ₄	Fruit, leaf	Wang et al., 2013; Zhu et al., 2013
154	Benzyl benzoate	C ₁₄ H ₁₂ O ₂	Leaf	Zhu et al., 2013
155	Benzyl salicylate	C ₁₄ H ₁₂ O ₃	Leaf	Zhu et al., 2013
156	Hexyl benzoate	C ₁₃ H ₁₈ O ₂	Flower	Ge et al., 2014
157	Methyl salicylate	C ₈ H ₈ O ₃	Flower, leaf	Zhu et al., 2013; Ge et al., 2014
158	Methyl linoleate	C ₁₉ H ₃₄ O ₂	Fruit	Wang C. F. et al., 2016
159	Methyl linolenate	C ₁₉ H ₃₂ O ₂	Fruit	Zhu et al., 2013; Wang C. F. et al., 2016
160	Linolenyl alcohol	C ₁₈ H ₃₂ O	Fruit	Wang et al., 2013
161	Ethyl linolenate	C ₂₀ H ₃₄ O ₂	Leaf	Zhu et al., 2013
162	Methyl palmitate	C ₁₇ H ₃₄ O ₂	Flower, fruit, leaf	Zhu et al., 2013; Ge et al., 2014; Wang C. F. et al., 2016
163	Methyl stearate	C ₁₉ H ₃₈ O ₂	Fruit	Wang C. F. et al., 2016
164	Ethyl butyrate	C ₆ H ₁₂ O ₂	Leaf	Zhu et al., 2013
165	Octyl formate	C ₉ H ₁₈ O ₂	Leaf	Zhu et al., 2013
166	Heptacosanoic acid methyl ester	C ₂₈ H ₅₆ O ₂	Fruit	Wang C. F. et al., 2016

been proven in various diabetic complications, such as retinopathy, nephropathy, neuropathy, and cardiomyopathy, with the pathogenesis generally linked to hyperglycemia-induced oxidative stress and inflammation and apoptosis (Farkhondeh et al., 2019). Kaempferol supplementation showed bone-sparing effects in newborn rats, glucocorticoid-induced and ovariectomy-induced osteoporotic models as well as bone fracture models (Wong et al., 2019).

Volatile constituents

The volatile components of *P. fortuneana* are diverse in different precious investigations, mainly including aldehydes, ketones, alcohols, alkanes, alkenes, esters, and terpenes. More

than 60 compounds were identified from the flower volatile oil of *P. fortuneana* by gas chromatograph–mass spectrometer (GC–MS), accounting for 83.77% of the total volatile oil, containing a variety of biologically active components, including terpenes and their oxygenated derivatives (50.31%), alkanes (18.52%), and aldehydes (5.54%) (Ge et al., 2014). A total of 32 compounds were identified from the volatile oil of fruits of *P. fortuneana*, accounting for 71.97% of the total volatile oil, mainly terpenes and alkanes (Wang et al., 2013). A total of 69 compounds were identified from the volatile oil of leaves of *P. fortuneana*, accounting for 80.52% of the total volatile oil (Zhu et al., 2013).

Terpenoids refer to olefinic compounds whose molecular formula is an integer multiple of isoprene. They are natural hydrocarbons that widely exist in plants. Many terpenoids have

TABLE 4 The chemical constituents of others constituents.

No.	Compound name	Formula	Plant part	References
Saccharides				
167	Xylose	C ₅ H ₁₀ O ₅	Fruit	Han et al., 2015; Yuan C. F. et al., 2016; Yao et al., 2020
168	Arabinose	C ₅ H ₁₀ O ₅	Fruit	Han et al., 2015; Yuan C. F. et al., 2016; Yao et al., 2020
169	Fucose	C ₆ H ₁₂ O ₅	Fruit	Yuan C. F. et al., 2016; Yao et al., 2020
170	Rhamnose	C ₆ H ₁₂ O ₅	Fruit	Han et al., 2015; Yuan C. F. et al., 2016; Yao et al., 2020
171	Mannose	C ₆ H ₁₂ O ₆	Fruit	Han et al., 2015; Yuan C. F. et al., 2016
172	Glucose	C ₆ H ₁₂ O ₆	Fruit	Yuan C. F. et al., 2016; Yao et al., 2020
173	Galactose	C ₆ H ₁₂ O ₆	Fruit	Yuan C. F. et al., 2016; Yao et al., 2020
174	Sorbose	C ₆ H ₁₂ O ₆	Fruit	Han et al., 2015; Yao et al., 2020
175	Fructose	C ₆ H ₁₂ O ₆	Fruit	Han et al., 2015
176	Glucuronic acid	C ₆ H ₁₀ O ₇	Fruit	Yuan C. F. et al., 2016
177	Galacturonic acid	C ₆ H ₁₀ O ₇	Fruit	Yuan C. F. et al., 2016
178	Ribose	C ₅ H ₁₀ O ₅	Fruit	Yuan C. F. et al., 2016
Lipid-Soluble vitamins				
179	δ-Tocopherol	C ₂₇ H ₄₆ O ₂	Fruit	Keser, 2014
180	α-Tocopherol	C ₂₉ H ₅₀ O ₂	Fruit	Keser, 2014
181	Vitamin K	C ₃₁ H ₄₆ O ₂	Fruit	Keser, 2014
182	Vitamin D	C ₂₈ H ₄₄ O	Fruit	Keser, 2014
Phytosterol				
183	β-Sitosterol	C ₃₁ H ₅₂ O ₂	Fruit	Keser, 2014
184	Ergosterol	C ₂₈ H ₄₄ O	Fruit	Keser, 2014
185	Stigmasterol	C ₂₉ H ₄₈ O	Fruit	Keser, 2014
186	4,5-Epoxycholestane	C ₂₇ H ₄₆ O	Fruit	Wang C. F. et al., 2016
187	Cholesterol	C ₂₇ H ₄₆ O	Fruit	Wang C. F. et al., 2016
188	Cholic acid ethyl ester	C ₂₆ H ₄₄ O ₅	Fruit	Wang C. F. et al., 2016
189	Stanozolol	C ₂₁ H ₃₂ N ₂ O	Fruit	Wang C. F. et al., 2016
Phospholipids				
190	Phosphatidic acid	C ₃₅ H ₆₈ NaO ₈ P	Fruit	Dong, 2002
191	Phosphatidylethanolamine	C ₉ H ₁₈ NO ₈ P	Fruit	Dong, 2002
192	Phosphatidylinositol	C ₄₁ H ₇₉ O ₁₃ P	Fruit	Dong, 2002
193	Phosphatidylglycerol	C ₄₀ H ₇₇ O ₁₀ P	Fruit	Dong, 2002
194	Lysophosphatidylcholine	C ₁₀ H ₂₂ NO ₇ P	Fruit	Dong, 2002
195	Phosphatidylcholine	C ₄₄ H ₈₃ NO ₈ P	Fruit	Dong, 2002
Fatty acids				
196	Linolenic acid	C ₁₈ H ₃₀ O ₂	Fruit	Zhu et al., 2013; Han et al., 2015
197	Linoleic acid	C ₁₈ H ₃₀ O ₂	Fruit	Wang et al., 2013
198	Arachidonic acid	C ₂₀ H ₃₂ O ₂	Fruit	Dong, 2002
199	Linolenic acid	C ₂₀ H ₃₄ O ₂	Fruit	Dong, 2002
200	Oleic acid	C ₁₈ H ₃₄ O ₂	Fruit	Dong, 2002
201	Erucic acid	C ₂₂ H ₄₂ O ₂	Fruit	Dong, 2002
202	Quinic acid	C ₇ H ₁₂ O ₆	Fruit	Wang et al., 2019
203	Malic acid	C ₄ H ₆ O ₅	Fruit	Wang et al., 2019
204	Arachidic acid	C ₂₀ H ₄₀ O ₂	Fruit	Dong, 2002
205	Behenic acid	C ₂₂ H ₄₄ O ₂	Fruit	Dong, 2002
206	Palmitic acid	C ₁₆ H ₃₂ O ₂	Fruit	Wang et al., 2013; Zhu et al., 2013; Ge et al., 2014; Keser, 2014
207	Stearic acid	C ₁₈ H ₃₆ O ₂	Fruit	Dong, 2002

(Continued)

TABLE 4 Continued

No.	Compound name	Formula	Plant part	References
208	Caproic acid	C ₆ H ₁₂ O ₂	Leaf	Zhu et al., 2013
209	Decanoic acid	C ₁₀ H ₂₀ O ₂	Flower	Ge et al., 2014
210	Lauric acid	C ₁₂ H ₂₄ O ₂	Fruit, leaf	Wang et al., 2013; Zhu et al., 2013
211	Myristic acid	C ₁₄ H ₂₈ O ₂	Flower	Dong, 2002; Ge et al., 2014
212	Pentadecaenoic acid	C ₁₅ H ₂₈ O ₂	Fruit	Dong, 2002
213	3-Hydroxydodecanoic acid	C ₁₂ H ₂₄ O ₃	Fruit	Wang C. F. et al., 2016
214	trans-3-Hexenoic acid	C ₆ H ₁₀ O ₂	Leaf	Zhu et al., 2013
215	trans-2-Hexenoic acid	C ₆ H ₁₀ O ₂	Leaf	Zhu et al., 2013
Phenylpropanoids				
216	Coumarin	C ₉ H ₆ O ₂	Leaf	Sharifi-Rad et al., 2021
217	4-Hydroxybenzaldehyde	C ₇ H ₆ O ₂	Leaf	Sharifi-Rad et al., 2021
218	Schisandrol B	C ₂₃ H ₂₈ O ₇	Leaf	Sharifi-Rad et al., 2021
219	3-(β-d-glucopyranosyloxy)-1-(4-hydroxy-3,5-dimethoxyphenyl)-1-propanone	C ₁₇ H ₂₄ O ₁₀	Leaf	Shim et al., 2020
Alkaloids				
220	Cinchonain I	C ₂₄ H ₂₀ O ₉	Fruit	Wang et al., 2019
221	Indole	C ₈ H ₇ N	Flower, leaf	Zhu et al., 2013; Ge et al., 2014
222	Stearic acid hydrazide	C ₁₈ H ₃₈ N ₂ O	Fruit	Wang C. F. et al., 2016

important physiological activities and are important for the research of natural products and the development of new drugs source (González-Burgos and Gómez-Serranillos, 2012; Peng et al., 2022). The previous studies have showed that the different growing parts of the *P. fortuneana* contain different terpenoids. Terpenoids in flowers of the *P. fortuneana* include isolekene (91), isophorone (92), farnesol (132), farnesyl acetone (133), and *trans*-nerolidol (152) (Ge et al., 2014). Terpenoids endemic to the fruits of *P. fortuneana* include isoterpinolene (101), menthol (102), and bicyclosesquiphellandrene (103) (Wang et al., 2013). It is reported that the bright color of the fruits of *P. fortuneana* is mainly due to its rich content of carotene (100) and lycopene (140) (Humbeck et al., 1989). In addition, the leaves of *P. fortuneana* also contains megastigmatrienone (104), α-calacorene (105), α-ionone (106), α-muurolene (107), α-pinene (108), α-terpinene (109), β-cubebene (110), and isophytol (148) (Zhu et al., 2013). It is reported that Jasmone (94), *trans*-squalene (101), and geraniol (151) present in both flowers and leaves of *P. fortuneana* (Zhu et al., 2013; Ge et al., 2014). The terpenes present in flowers, fruits and leaves of the *P. fortuneana* are mainly α-Cubebene (93), α-terpineol (96) and β-ionone (97), respectively (Wang et al., 2013; Zhu et al., 2013; Ge et al., 2014). Co-administration of geraniol with methotrexate may attenuate methotrexate-induced acute kidney injury (Younis et al., 2021). The β-ionone could prevent stress-induced skin aging *via* inhibition of GR signaling in human dermal fibroblasts (Choi et al., 2021). The α-pinene activates natural killer (NK) cells and increases NK cells cytotoxicity,

suggesting it is a potential compound for cancer immunotherapy (Jo et al., 2021).

The alkanes in *P. fortuneana* include octane (116), nonane (117), decane (118), n-pentadecane (119), docosane (120), tricosane (121), pentacosane (123), tetracosane (127), and other straight-chain alkanes (Wang et al., 2013; Zhu et al., 2013; Ge et al., 2014; Wang C. F. et al., 2016). Among these aldehydes, ketones, and alcohol components, benzyl alcohol is mostly as fragrance ingredients and preservatives in cosmetic products (Johnson et al., 2017). It was reported that linalool odor-induced analgesia was triggered through a TRPA1-independent pathway in mice (Kashiwadani et al., 2021). Decanal could protect human dermal fibroblasts against UVB-induced photoaging *via* the cAMP pathway (Kang et al., 2020), and the 2-hexenal inhibit *Aspergillus flavus* spore germination involving disruption of mitochondrial energy metabolism and induction of early apoptosis (Ma et al., 2019). The volatile esters in *P. fortuneana* are mainly benzoates, such as benzyl benzoate (154), benzyl salicylate (155), hexyl benzoate (156), and methyl salicylate (157), and fatty acid derivatives, such as ethyl linolenate (161), octyl formate (165), and heptacosanoic acid methyl ester (166) (Zhu et al., 2013; Ge et al., 2014; Wang C. F. et al., 2016). The main components of fruit oil in *P. fortuneana* are methyl linoleate (158) (18.7%), methyl linolenate (159) (22.8%), methyl palmitate (162) (20.3%), and methyl stearate (163) (4.6%), and interestingly, the content is higher than other common edible oils and fats currently on the market (Wang C. F. et al., 2016). The chemical constituents of volatile constituents

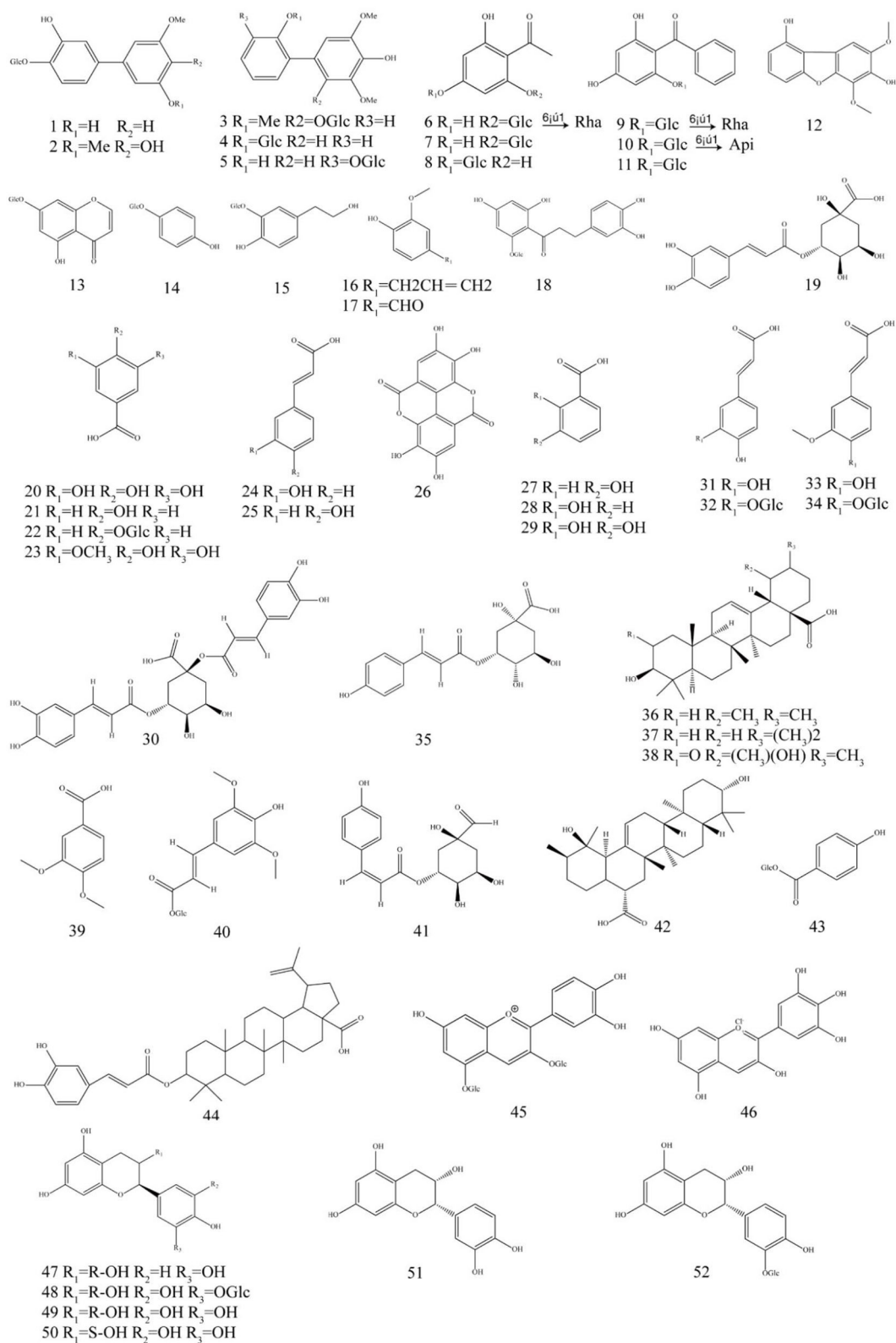


FIGURE 3
Chemical structures of phenolics in *P. fortuneana*.

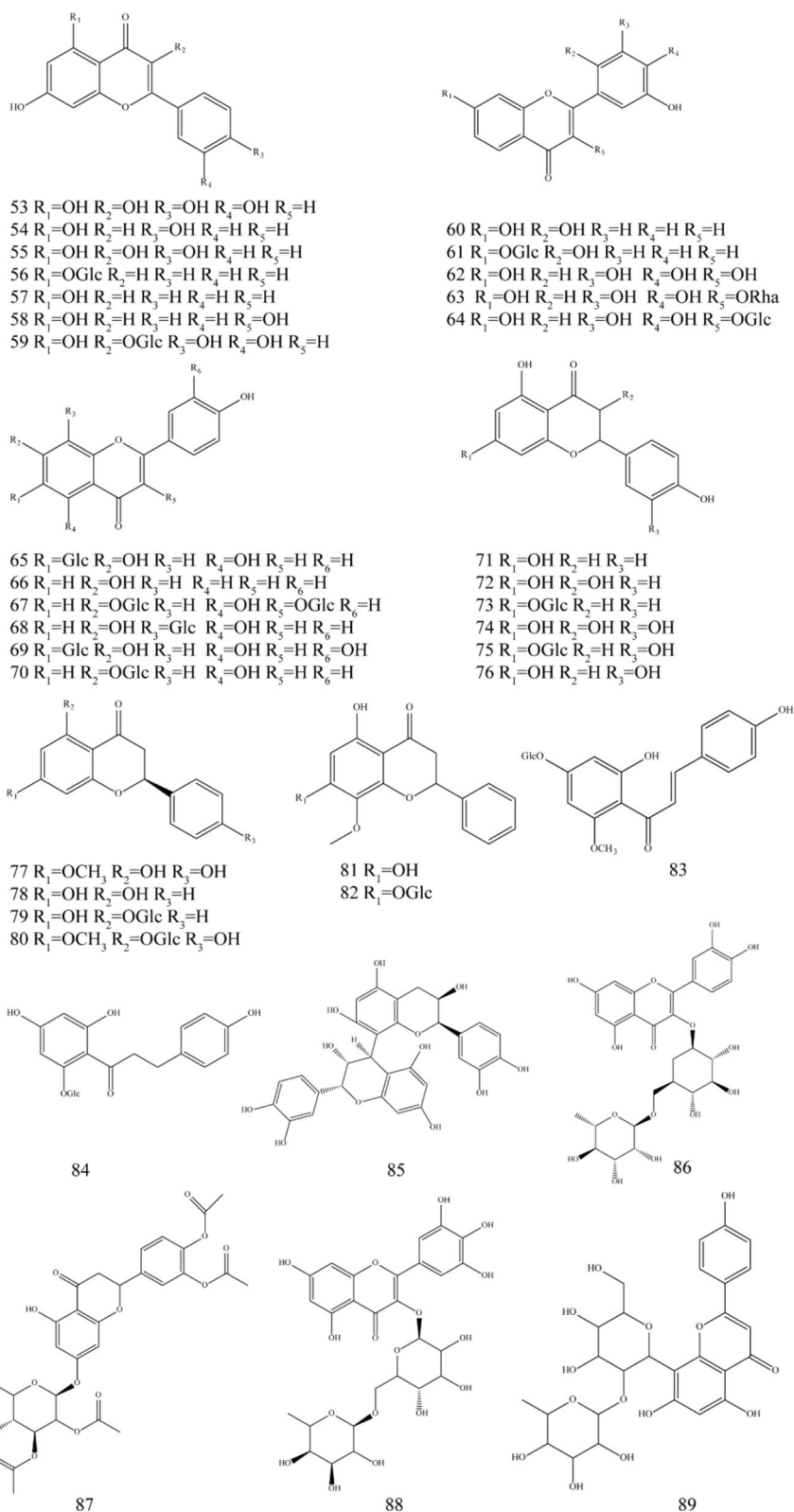


FIGURE 4
 Chemical structures of flavonoids in *P. fortuneana*.

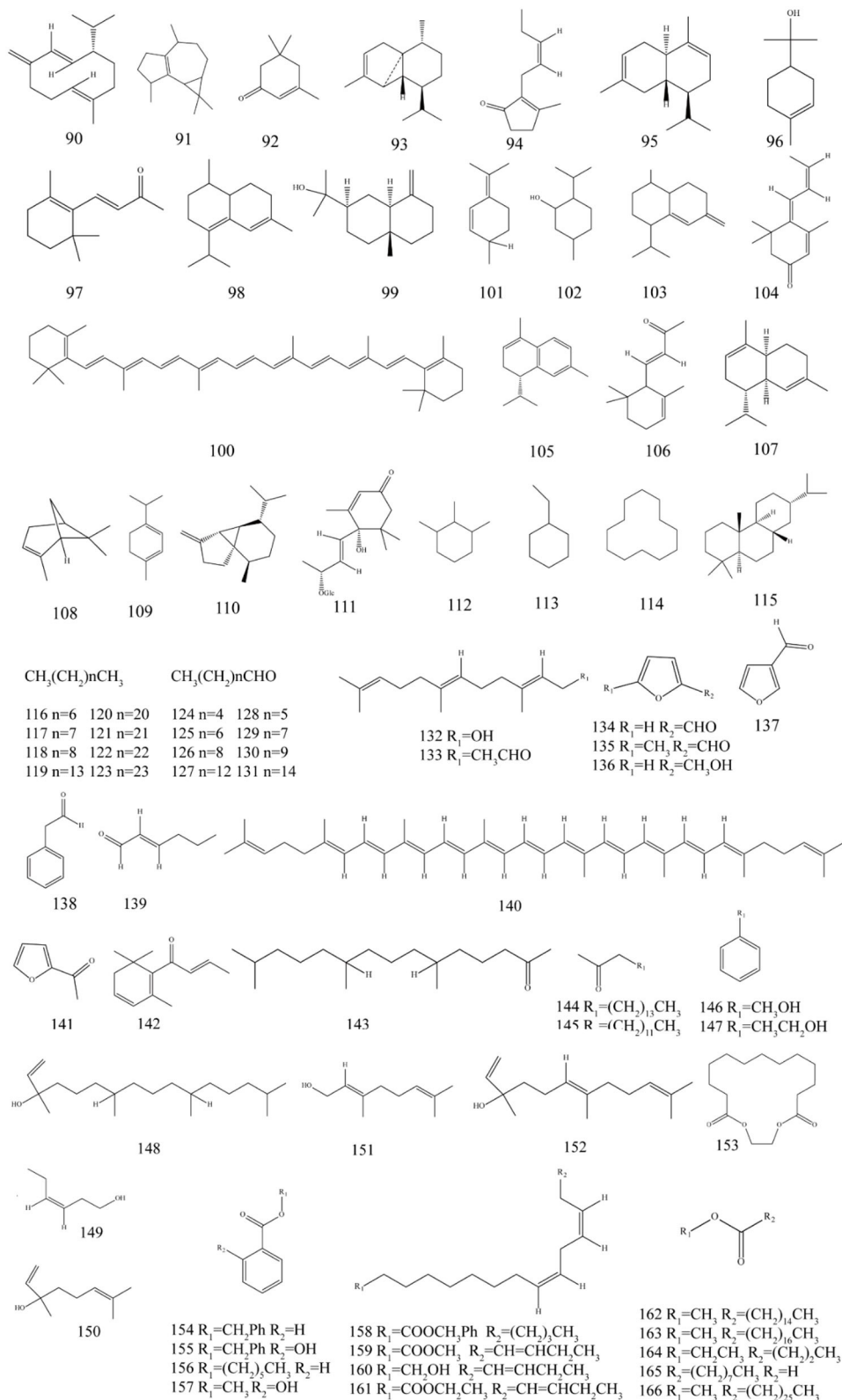


FIGURE 5
Chemical structures of volatile constituents in *P. fortuneana*.

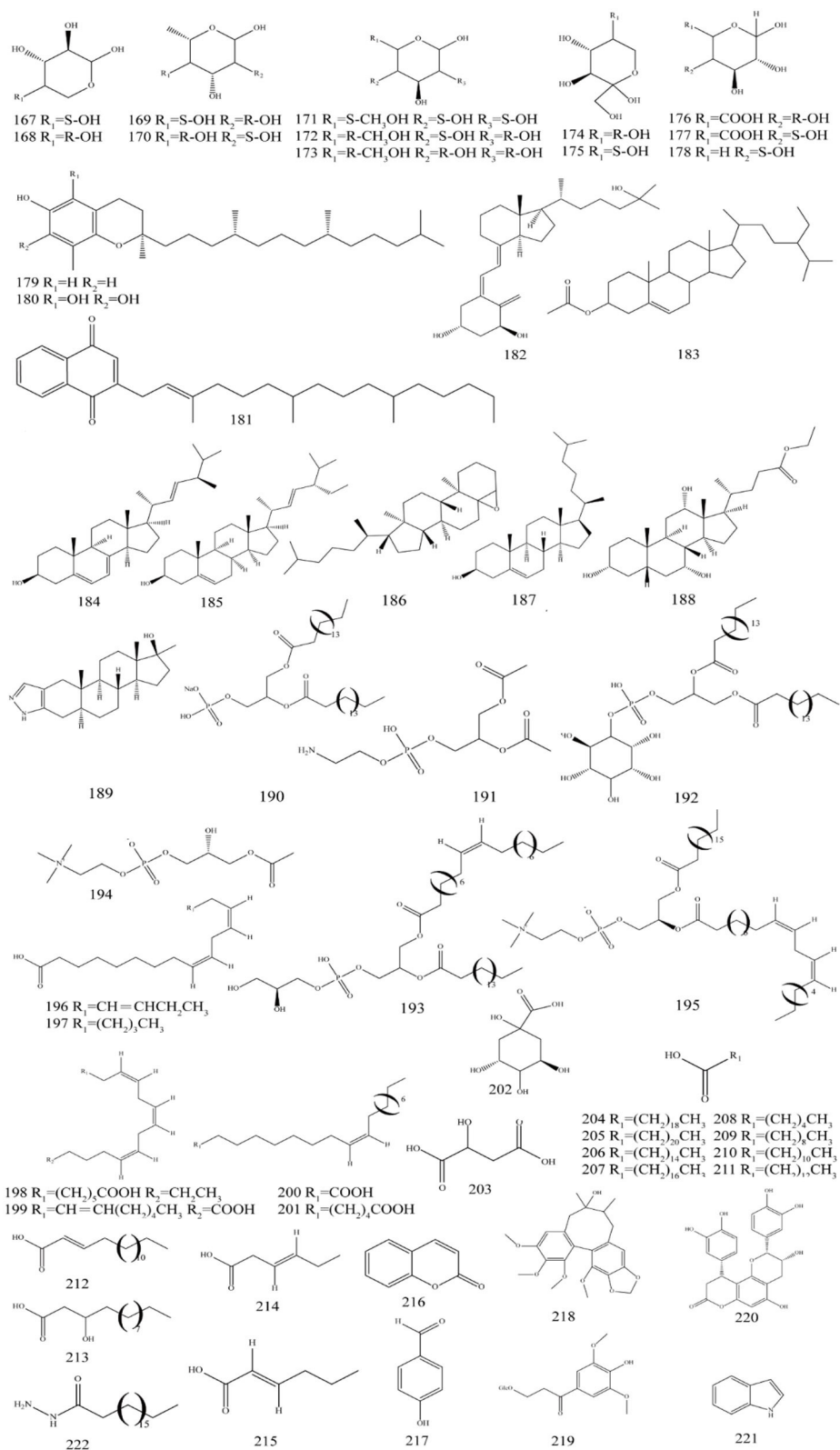


FIGURE 6
Chemical structures of other compounds in *P. fortuneana*.

and their corresponding structures are exhibited in Table 3 and Figure 5.

Other compounds

Besides compounds mentioned above *P. fortuneana* also contains other compounds such as polysaccharides, dietary fiber, phytosterols, and organic acids (Table 4, Figure 6). The polysaccharides in *P. fortuneana* have various bioactivities such as antimutagenic, immunomodulatory, and antioxidant effects. It was reported that PP-A2, PP-A3, and PP-A4; and PP-B1, PP-B2, and PP-B36 fractions were separated from the fruits of *P. fortuneana* by fractional precipitation, DE-52 column chromatography. Separated by SephadexG-200 column analysis and identification, PP-A2, PP-A3, and PP-B2 are homogeneous polysaccharides (Yang et al., 2004). The molecular mass of PP-A2 is 30 kDa, and its monosaccharide component is mainly a heteropolysaccharide composed of arabinose (168) and rhamnose (170), which also contains a small amount of mannose (171), galactose (173), and fructose (175). The ratio of the PP-A2 substances is as follows: (Arabinose + Rhamnose):Fructose:Galactose:Mannose = 9.56:3.37:1.88:1 (Huang et al., 2007b). Also, PP-A3 is a glycoprotein with a molecular mass of 210 kDa, mainly composed of arabinose, which contains a small amount of glucose (172), and fructose. The ratio of the amount of PP-A3 is Arabinose:Glucose:Fructose = 1:62:1:1.59, in which the total amino acid content is 0.5% (Huang et al., 2007a). High-performance liquid chromatography (HPLC) analysis revealed that Se-conjugated polysaccharides from *P. fortuneana* (Se-PPFs) were heteropolysaccharides composed of xylose (167) (29.8%), arabinose (23.2%), fucose (169) (25.7%), mannose (4.1%), glucuronic acid (176) (2.9%), galacturonic acid (177) (3.2%), ribose (178) (1.8%), rhamnose (3.8%), glucose (2.2%), and galactose (3.3%), respectively (Yuan C. et al., 2016).

Dietary fiber is described as supporting laxation, attenuating blood glucose responses and assisting with cholesterol-lowering. The different types of dietary fiber have various effects (Fuller et al., 2016). The monosaccharide components of the dietary fiber from *P. fortuneana* are mainly xylose, arabinose, rhamnose, and sorbose (174), and also contain a small amount of fructose and mannose, of which the content of xylose is the highest (33.56%). The physicochemical properties of dietary fiber of *P. fortuneana* fruit showed that *P. fortuneana* dietary fiber exhibited good water and oil holding capacity, and also had strong absorption capacity for glucose, while in terms of solubility and swelling were relatively insufficient (Han et al., 2015).

The lipid-soluble vitamins and phytosterol levels of *P. fortuneana* extracts were δ -Tocopherol (179) (0.13 mg/kg), α -tocopherol (180) (31.02 mg/kg), vitamin K (181) (0.68 mg/kg), and vitamin D (182) (4.13 mg/kg). Moreover, β -sitosterol (183)

(122.25 mg/kg), ergosterol (184) (4.57 mg/kg), stigmasterol (185) (7.25 mg/kg), 4,5-epoxycholestane (186), cholesterol (187), cholic acid ethyl ester (188), and stanozolol (189) are the phytosterols found in *P. fortuneana* (Keser, 2014; Wang C. F. et al., 2016). Vitamin E in *P. fortuneana* seed oil is positively correlated with soil Ca and Mg content, as well as linoleic acid and soil phosphorus content (Tang et al., 2007).

Lipids are one of the important nutrients that the human body needs, and they provide the energy and essential fatty acids that the human body needs (Yoon et al., 2021). The major fatty acids in the *P. fortuneana* extract were linolenic acid (196) (45.91%), quinic acid (202), malic acid (203), palmitic acid (206) (29.10%), caproic acid (208), decanoic acid (209), myristic acid (211), and trans-2-hexenoic acid (215) (Wang et al., 2013; Zhu et al., 2013; Ge et al., 2014). Phospholipids have the functions of improving nerve dysfunction, enhancing memory and anti-aging (Tayebati, 2018). A total of six phospholipid components were detected from the fruits of *P. fortuneana*, and phosphatidic acid (190) was the main component that is accounting for more than 80% of the total phospholipids (Dong, 2002).

Besides, *P. fortuneana* also contains a small number of phenylpropanoid compounds such as coumarin (216), 4-hydroxybenzaldehyde (217), and Schisandrol B (218) (Sharifi-Rad et al., 2021). Alkaloids contain Cinchonain I (220), indole (221), and stearic acid hydrazide (222) (Wang et al., 2013, 2019; Ge et al., 2014).

Pharmacological properties

The pharmacological effects of *P. fortuneana* are mainly reflected in the aspects of immune regulation, TYR inhibition, anti-oxidation, anti-tumor, inflammatory, and antimutagenic effects (Table 5, Figures 7–9).

Antioxidant

The peroxide value (POV) of oil determined by the oven storage method showed that the antioxidant activity of total flavonoids of *P. fortuneana* fruit was higher than Vc and citric acid (Han and Zhang, 2019). Both crude extracts and purified flavonoids from the fruits of *P. fortuneana* could increase the antioxidant capacity of various vegetable and animal oils and all had a dose–effect relationship with the concentration. The flavonoids from *P. fortuneana* can inhibit the hydrolysis of oil rancidity into free fatty acids (Wang et al., 2015a). The same effect was also observed in the polysaccharide from *P. fortuneana* (Wang X. J. et al., 2016). The content of flavonoids in the fruits of *P. fortuneana* with lower maturity is higher. In the auto-oxidation system of 2,2-diphenyl-1-picrylhydrazyl (DPPH) and pyrogallol, the flavonoids from *P. fortuneana* have a significant scavenging effect on DPPH \cdot and superoxide free

TABLE 5 The pharmacological Effects of *P. fortuneana*.

Pharmacological effects	Detail	Extracts/Compounds	Models	Dose/Concentration	References
Immunomodulatory					
	Protects the thymus and spleen	<i>P. fortuneana</i> haematochrome	CTX intraperitoneal injection mice	200, 400, 800 mg/kg	Xu and Zha, 2013
	Enhanced phagocytosis of mouse peritoneal macrophages				
	Improve humoral immune function				
	↑Spleen lymphocyte proliferation and NK cells activity, CD4 ⁺ /CD8 ⁺ T cells, IL-2, Nrf2, SOD, GPx ↓IL-6, TNF-α	<i>P. fortuneana</i> polysaccharides	–	100, 200, 300 mg/kg	Yuan et al., 2010
	↑Indices of spleen and thymus, NK cells activity, GPx, SOD, Nrf2	selenium-enriched green tea polysaccharides and <i>P. fortuneana</i> polysaccharides are used in combination	–	300 mg/kg	Yuan et al., 2015a
	↓IL-6, TNF-α, MDA, ALT, AST				
Tyrosinase inhibition					
	↓TYR, melanin production	<i>P. fortuneana</i> extracts	B16 cells	6.25, 12.5, 25, 50, 100 μg/ml	He et al., 2011
	↓Histamine release		Rat peritoneal mast cells		
	↓Melanin production, TYR, ROS	<i>P. fortuneana</i> extracts of leaf	B16F10 mouse melanoma cells	100, 250 μg/ml	Shim et al., 2020
	↓TYRP-1, TYRP-2, TYR, MITE, PAX3	3,4-Dihydroxy-5-methoxybiphenyl-2'-O-β-D-glucopyranoside	Human Epidermal Melanocytes	60, 80, 100 μM	Lin et al., 2015
Antioxidant					
	Improve chemical stability, bioavailability and solubilization of quercetin to produce antioxidant effect	<i>P. fortuneana</i> proanthocyanidin	H ₂ O ₂ induced HepG ₂	–	Zhao et al., 2015
	↑GPx, SOD	<i>P. fortuneana</i> extracts of fruit	D-gal and bromobenzene subcutaneously intraperitoneally injected into mice	400 mg/kg	Xu et al., 2016
	↓MDA, ALT, AST				
	↓Lipid peroxidation in mouse liver homogenate	<i>P. fortuneana</i> polysaccharides	Fe ²⁺ -H ₂ O ₂ -induced healthy mice liver tissue	500, 1,000, 2,000, 3,000 μg/ml	Zhao et al., 2012
	↓MDA		0.15% CCL ₄ intraperitoneally injected into mice	50, 100, 200 mg/kg	
	↑SOD, GSH, GPx	<i>P. fortuneana</i> fruit powder	D-galactose 80 mg/kg subcutaneous injection into nape	15, 30%	Hou et al., 2003b
	↓MDA				
	↑SOD, GSH, GPx	<i>P. fortuneana</i> fruit powder	D-galactose 100mg/kg subcutaneous injection into nape	20, 80 mg/kg	Qin and Wei, 2011
	↓MDA, MAO				
	↓MDA, ALT	<i>P. fortuneana</i> extracts of fruit	Restraint stress treatment	125, 250, 500 mg/kg	Xu et al., 2007

(Continued)

TABLE 5 Continued

Pharmacological effects	Detail	Extracts/Compounds	Models	Dose/Concentration	References
Anti-tumous effect					
	↑Cleavage of PARP and Caspase-3, Caspase-9, E-cadherin, Cytokeratin 19	Se-conjugated polysaccharides from <i>P. fortuneana</i>	HEY and SKOV3 cells HEY cells subcutaneously injected into nude mice	200, 400 μg/ml 400 mg/kg	Sun et al., 2016
	↓β-catenin, Cyclin D1, Bcl-2, MMP-9, N-cadherin, ZEB1, ZEB2, Viementin				
	↑p53, Bax, Puma, Noxa, Bax/Bcl2, Caspase3/9	Se-conjugated polysaccharides from <i>P. fortuneana</i>	TNBC MDA-MB-231 cells MDA-MB-231 cells subcutaneously injected into nude mice	50, 100, 200, 400 μg/ml 100, 200, 400 μg/ml	Yuan C. F. et al., 2016
	↓CDC25C–CyclinB1/CDC2 pathway				
	↑ROS, DNA damage, Bax, Caspase-3	<i>P. fortuneana</i> polysaccharides	Skov3cells	100, 200 μg/ml	Yao et al., 2020
	↓MMP				
	↑ROS, Bax, γ-H2AX, RAD51	<i>P. fortuneana</i> polysaccharide-iron	Skov3cells	100, 200, 400 μg/ml	Li et al., 2021
	↓Bcl-2, MMP				
Anti-hyperlipidemic					
	↑HDL-C	<i>P. fortuneana</i> extracts of fruit	High-fat and high-cholesterol diet fed mice	5%	Xu et al., 2016
	↓TC, TG, LDL-C				
Regulate intestinal flora					
	↑Actinobacteria, Bacteroidaceae, Corynebacteriaceae, S24-7, Lactobacillaceae	<i>P. fortuneana</i> extracts of fruit	High-fat diet fed mice	0.4, 1%	Xu et al., 2019
	↓Lactulose/mannitol ratio, GLUT2, digestive enzyme activities, Clostridia, Ruminococcaceae, Oscillospira, Flexispira				
Protect renal					
	↑Body weight, GSH, GPx, SOD, CAT, GR, Bcl-2, Nrf2, HO-1, γ-GCS, NQO1	<i>P. fortuneana</i> extracts of fruit	CdCl ₂ injected mice	250 mg/kg	Ke et al., 2019
	↓Cd, kidney weight, MDA, NO, plasma uric acid, urea, creatinine, Bax, TNF-α, Keap-1				
Liver protection					
	↑GPx, T-AOC, Nrf2, CAT	<i>P. fortuneana</i> polysaccharides	30% CCl ₄ subperitoneally injected to rats	200, 400 mg/kg	Yuan C. et al., 2016
	↓ALT, AST, MDA				
	↑SOD, GPx, GSH, CAT	Se-conjugated polysaccharides from <i>P. fortuneana</i>		200, 400 mg/kg	Yuan et al., 2015b
	↓ALT, AST, LDH, TC, TG, H ₂ O ₂ , TBAR				

(Continued)

TABLE 5 Continued

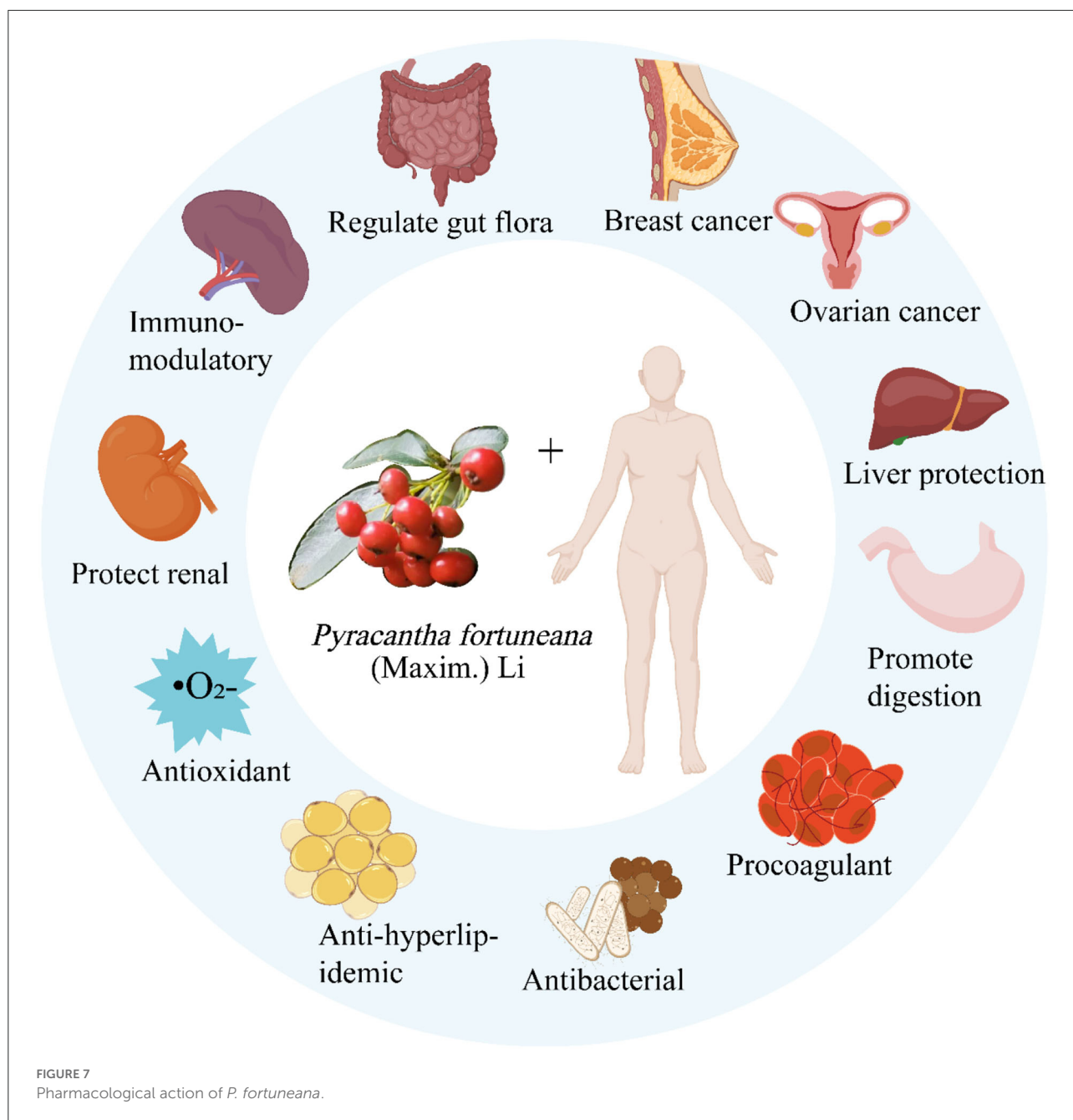
Pharmacological effects	Detail	Extracts/Compounds	Models	Dose/Concentration	References
Antimutagenesis	↑ SOD, GPx ↓ Micronucleus formation in bone marrow and peripheral blood, CYP4501A	Se-conjugated polysaccharides from <i>P. fortuneana</i>	CP induced mice	1,350, 2,700, 5,400 mg/kg	Peng et al., 2016
Anti-inflammatory	Analgesic, anti-inflammatory	<i>P. fortuneana</i> ethanol extract	Formalin subcutaneously injected into rat Carrageenan injected into rat	100, 300 mg/kg	Taheri et al., 2021

↑ means promote, ↓ means inhibit.

radicals(O_2^-). The antioxidant activity of the purified flavonoids from fruits of *P. fortuneana* was enhanced compared with that before purification (Li and Chen, 2013). Also, *P. fortuneana* flavonoids have stronger scavenging effects on 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) and DPPH• than propyl gallate (Li W. et al., 2013). The statistical analysis shows that flavonoids from *P. fortuneana* and V_C compounds have synergistic antioxidant effects in inhibiting lipid oxidation, scavenging hydroxyl radicals (OH^-) and O_2^- . In addition, the combination of V_C and flavonoids from *P. fortuneana* have superior antioxidant activity than V_C or flavonoids alone. When the mass concentration was 0.25 mg/ml, the protection rates of flavonoids from *P. fortuneana*, flavonoids from *P. fortuneana* + V_C were 93.20 and 93.62% for vegetable oils; and 70.20 and 75.28% for animal oils, respectively. When the mass concentration is 0.65 mg/ml, the scavenging rates of the compound solution to OH^- and O_2^- were 27.61 and 31.02% (Wang et al., 2015b).

The extracts of different polar parts from the fruits of *P. fortuneana* have antioxidant activities, and the antioxidant activities of the extracted parts have a good correlation with the total polyphenol content. Among them, the water fraction extract DPPH• and ABTS⁺ had the highest free radical scavenging rates, with IC₅₀ values of 0.76 ± 0.03 mg/ml and 1.71 ± 0.10 mg/ml, respectively, the ferric ion reducing antioxidant power (FRAP) value of the ethyl acetate site was the highest, 382.20 ± 4.72 μmol Fe²⁺/g dry sample; The total phenolic content of the n-butanol was the highest, which was $2,763 \pm 3.91$ mg GAE/100 g dry sample (Weng and Gao, 2015). The scavenging activity of the ethanol, methanol and acetone extracts of *P. fortuneana* on ABTS⁺ is higher than butylated hydroxytoluene (BHT). The scavenging activity of the methanol and ethanol extracts of *P. fortuneana* on DPPH• and OH^- is higher than BHT (Keser, 2014). The strongest DPPH•, ABTS⁺ scavenging activity and Fe³⁺ reducing power were observed in the 50% acetone extract of *P. fortuneana* with IC₅₀ values of 0.61, 0.74, and 2.98 mg DM/ml (Wang et al., 2019).

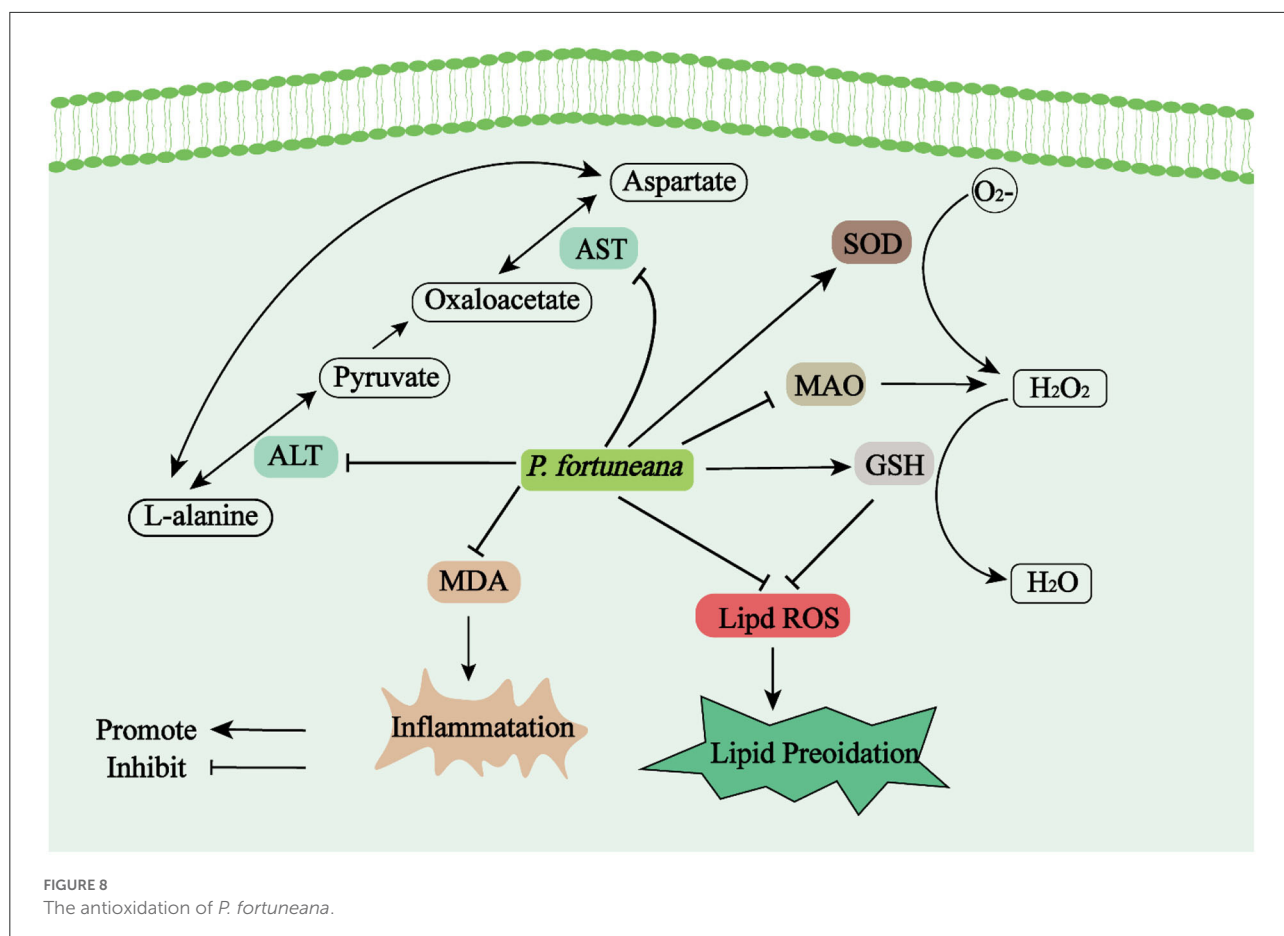
As shown in Figure 8, the extracts from the fruits of *P. fortuneana* extract alleviates oxidative stress in the D-gal and bromobenzene-injured model mouse via enhancing endogenous antioxidant activity. It can enhance the activity of glutathione peroxidase (GPx) and superoxide dismutase (SOD), inhibit the increase of alanine aminotransferase (ALT), malondialdehyde (MDA), and the aspartate aminotransferase (AST) (Xu et al., 2016). Another experiment showed adding the fruit powder of *P. fortuneana* to the diet can reduce the increase of MDA content in heart, liver and brain of D-gal induced mice. In addition, the fruit administration orally also enhanced SOD activity of red blood cells, liver and brain, increased GPx, and glutathione (GSH) in whole-blood and liver, and improved thymus gland index (Hou et al., 2003b). In addition, the fruit powder treatment can also reduce the activity of monoamine oxidase (MAO) in the hippocampus of



mice (Qin and Wei, 2011). The *P. fortuneana* fruit extract (PFE) has a certain protective effect on liver injury caused by restraint stress treatment *via* scavenging reactive oxygen species (ROS) and inhibiting lipid peroxidation (Xu et al., 2007).

The polysaccharides from *P. fortuneana* (PFPs) (10 mg/ml) had a scavenging rate of 67.13% against metal ions; the scavenging effect of PFPs against DPPH was 93.5% at 8 mg/ml; in addition, the PFPs also showed scavenging activity against ABTS⁺ radical and O₂⁻ at concentration of 1–4 mg/ml (Yao et al., 2020). Yuan et al. reported that PFPs significantly increase

splenocyte GPx and SOD activities and reduce MDA levels (Yuan et al., 2010). In addition, it is reported that PFPs can effectively scavenge O₂⁻ and OH⁻, and inhibit Fe²⁺-H₂O₂-induced lipid peroxidation of liver homogenate in healthy mice, and significantly reduce the level of MDA in the liver of CCL₄ liver-injured mice. The liver homogenate of the mice in the PFPs-treated group can significantly inhibit the lipid peroxidation induced *in vitro*, indicating that PFPs has the effect of scavenging oxygen free radicals and resisting lipid peroxidation (Zhao et al., 2012).



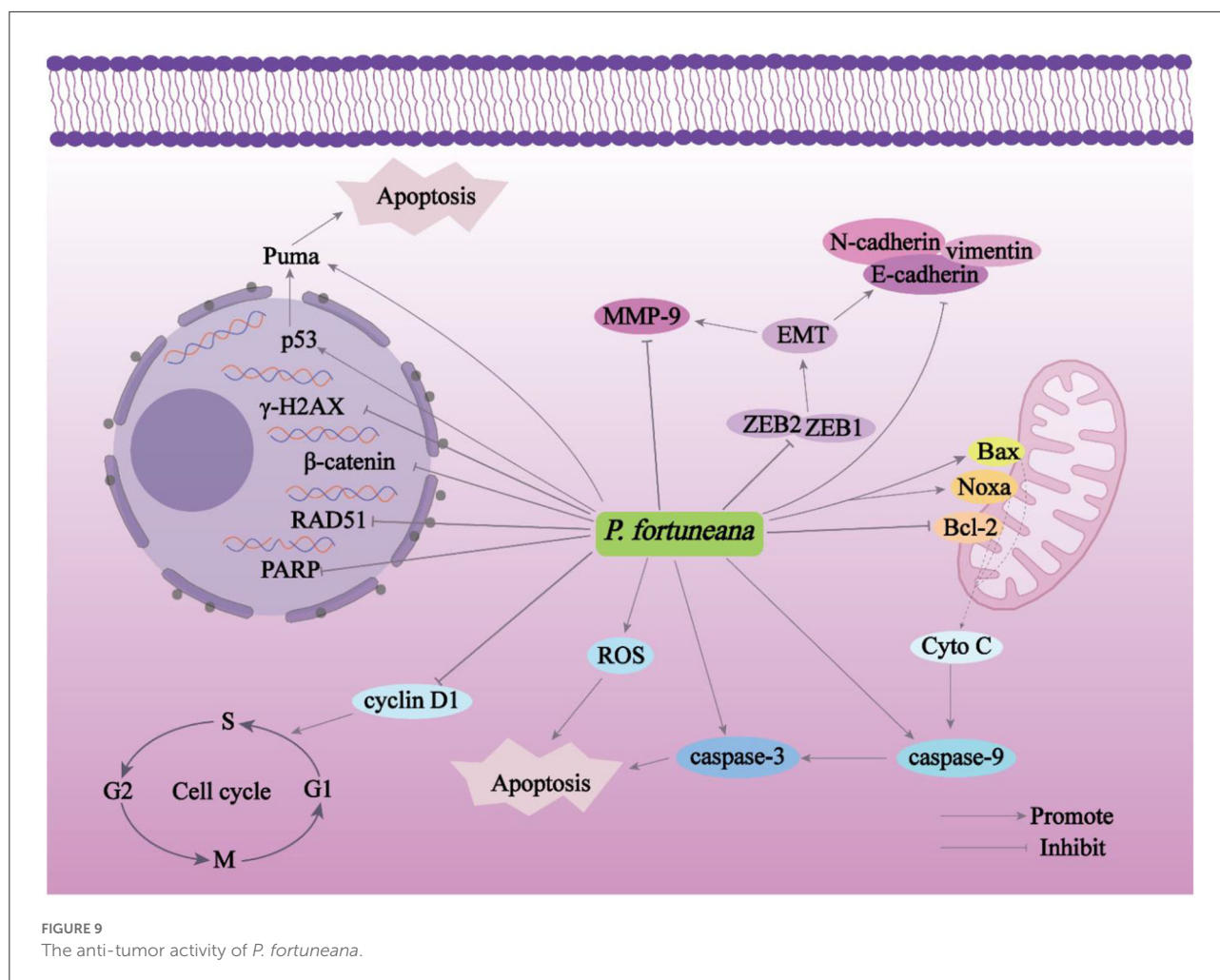
The antioxidant activity of *P. fortuneana* is also related to the non-extractable polyphenol (NEPP). The proportion of NEPP in total extractable polyphenol (TEPP) from *P. fortuneana* was relatively high as to 80.55%. The antioxidant capacity of ABTS⁺ and FRAP was positively correlated with the content of NEPP (Xu et al., 2015). The antioxidant capacity contributed by the proanthocyanidins in the fruits of *P. fortuneana* (PYFP) accounts for a large proportion of the total antioxidant capacity of its antioxidant extract (Yan et al., 2015). The previous reports showed that PYFP had strong scavenging effects on DPPH[•] and ABTS⁺ cationic free radicals (Zhang et al., 2014). In addition, PYFP can enhance the stability of small molecular polyphenols such as quercetin, improve bioavailability, and thus exert the antioxidant effect of co-ketones (Zhao et al., 2015). The red pigment from the fruits of *P. fortuneana* (RPP) purified by C₁₈ Sep-Pak column has IC₅₀ of 1.43, 3.13 mg/ml, and 3.43 g/ml for scavenging OH⁻, O₂⁻, and DPPH, respectively (Li P. X. et al., 2013).

Also, volatile oil from the fruits of *P. fortuneana* (VOPF) also has obvious scavenging effects on DPPH, and the scavenging effect of VOPF on sodium nitrite is better than BHT (Ge et al., 2014). According to the total reducing power and the scavenging ability of ABTS⁺ free radicals, the VOPF has a

certain antioxidant activity, and the antioxidant activity has a significant dose-effect relationship with the sample amount (Wang et al., 2013). In addition, *P. fortuneana* oil has good Fe²⁺ reducing ability, and its antioxidant activity increases with the increase of sample concentration (Wang C. F. et al., 2016).

Anti-tumor activity

As shown in Figure 9, the anticancer effect of *P. fortuneana* is mainly accomplished by promoting the apoptosis of cancer cells and inhibiting the migration of cancer cells (Figure 9). It was reported that polysaccharides from the fruits of *P. fortuneana* (PFPs) possessed cytotoxicities on the human ovarian carcinoma Skov3 cells *via* induction of apoptosis by upregulating Bax and caspase-3. Furthermore, PFPs can increase ROS, decrease mitochondrial membrane potential (MMOP), and damage DNA (detected as γ -H2AX and RAD51 foci) (Yao et al., 2020). Another report by Sun et al. reported that selenium (Se)-PFPs can induce the apoptosis of ovarian cancer cell lines (HY and Skov3) and inhibit their migration and invasion *via* downregulating cyclin D1, Bcl-2, and matrix metalloproteinase (MMP) 9; upregulating the cleavage (C) of



poly ADP-ribose polymerase (PARP) and C-caspase-3; and enhancing the activities of caspase-3 and -9. Furthermore, Se-PFPs inhibited epithelial to mesenchymal transition (EMT) of cancer cells by upregulating E-cadherin and cytokeratin 19, and downregulating N-cadherin, vimentin, zinc finger E-box binding homeobox (ZEB1)-1, and ZEB2. The further *in vivo* experiments also showed that Se-PFPs can reduce the β -catenin both in cytoplasmic and nuclear, and increased the phosphorylation of β -catenin (Sun et al., 2016). Li et al. reported that PFPs-iron complex (PPI) can induce apoptosis of Skov3 cells *via* reducing MMOP and increasing ROS, downregulating Bcl-2 and upregulating Bax. What's more, PPI can also result in DNA damage *via* upregulating γ -H2AX and RAD51 (Li et al., 2021).

Another experimental result showed that Se-PFPs (containing 93.7% of PFPs, 2.1% of uronic acid, and 3.7 μ g/g of Se) can inhibit triple negative breast cancer MDA-MB-231 cell growth dose-dependently by inducing G2 phase cell arrest *via* inhibiting CDC25C-CyclinB1/CDC2 pathway. In addition, Se-PFPs caused cancer cell apoptosis *via* upregulating p53, Bax,

Puma, and Noxa, downregulating Bcl2, and increasing activities of caspases-3 and -9. Furthermore, the antitumor effects of the Se-PFPs were confirmed using a *in vivo* mouse xenograph model (Yuan C. et al., 2016).

Immunomodulatory

Cyclophosphamide (CTX) was commonly used to induce experimental animal immune system damage. It is found that the red pigment from the fruits of *P. fortuneana* (RPP) has a good protective effect on the immune organs of the immunosuppressed mice induced by CTX, and can improve the phagocytic function of the peritoneal macrophages in immunosuppressed mice. What is more interesting is that RPP can also promote the formation of serum hemolysin and hemolytic plaques (Xu and Zha, 2013). Furthermore, PFPs can significantly increase the thymus and spleen index of mice, and promote splenocyte proliferation and increase the NK cell activity. The PFPs can increase the number of CD4 T cells and

CD4⁺/CD8⁺ ratio, as well as the interleukin-2 (IL-2) levels, reduce the levels of interleukin-6 (IL-6) and tumor necrosis factor- α (TNF- α). In addition, PFPs could upregulate the nuclear factor E2-related factor (Nrf2) in splenocytes (Yuan et al., 2010). The combined use of Se-enriched green tea polysaccharides and PFPs (Se-GTP+PFPs) has stronger immunomodulatory effects than PFPs alone. Besides increasing indices of spleen and thymus and NK cell activity and upregulating Nrf2, Se-GTP+PFPs can decrease the IL-6 and TNF- α . The Se-GTP+PFPs can also enhance the activities of GPx and SOD, and reduce the content of MDA in mice, suggesting that the combined administration of Se-GTP and PFPs can synergistically improve immune function and decrease oxidative stress by enhancing the clearance of free radicals (Yuan et al., 2015a).

Tyrosinase inhibition

Extracts from the fruits of *P. fortuneana* (PFE) can significantly inhibit TYR activity (IC₅₀ = 32.28 μ g/ml) and histamine release from rat abdominal mast cells. The PFE can reduce the content of melanin in mouse B16 cells (IC₅₀ = 82.47 μ g/ml), and have an inhibitory effect on TYR activity in B16 cells (IC₅₀ = 53.48 μ g/ml) (He et al., 2011). Using bioactivity-guided fractionation to screen constituents with alleviating effects against melanogenesis and oxidation from the fruits of *P. fortuneana*, seven compounds with inhibitory melanin production and TYR activity, ABTS⁺ and DPPH scavenging activities were isolated from the *n*-butanol extract of the fruits of *P. fortuneana*. Among them, *p*-hydroxybenzoic acid β -D-glucosylester (HG), and cimidahurinine (CH) have strong inhibitory effects on melanogenesis and TYR activity as well as ABTS⁺ and DPPH[•] scavenging activities. Furthermore, HG and CH can also inhibit the ROS production of B16F10 cells induced by tert-butyl hydroperoxide (TBHP), and western blot analysis revealed HG and CH downregulated the tyrosinase-related protein (TYRP)-1 and -2 (Shim et al., 2020). In 2015, Lin et al. reported that a new compound **13**, named 3,4-dihydroxy-5-methoxybiphenyl-21-O- β -D-glucopyranoside, isolated from the *P. fortuneana* had powerful TYR inhibitory activity in human epidermal melanocytes to achieve the effect of skin whitening *via* downregulating the expressions of TYRP, microphthalmia-associated transcription factor (MITF), and paired box 3 (PAX3) (Lin et al., 2015).

Hepatic protection

The Se-PFPs have protective effects on CCl₄-induced liver injury, and reduced the CCl₄ induced increase of ALT, AST, lactic dehydrogenase (LDH), cholesterol, and triglycerides in serum of mice. The Se-PFPs treatment elevated the activities of SOD, GPx, and levels of GSH in liver, and decreased the levels

of thiobarbituric acid reactive substances (TBAR) and H₂O₂ in liver which served as lipid peroxidation biomarkers, indicating that Se-PFPs can attenuate the CCl₄-induced liver injury. The mechanism underlying this effect mentioned above may be attributed to the reduction of oxidative stress and inflammation in the liver by Se-PFPs through increasing antioxidant system (Yuan et al., 2015b). Also, it is reported that PFPs can increase GPx and total antioxidative capacity (T-AOC) in liver tissue of CCl₄-induced mice, reducing MDA, and upregulating Nrf2 (Yuan C. et al., 2016).

Others

It was reported that proanthocyanidins from the fruits of *P. fortuneana* (PYFP) had an inhibitory effect against α -glucosidase (IC₅₀ = 0.15 \pm 0.01 μ g/ml) in a non-competitive type (Wei et al., 2017). Wang et al. investigated the inhibitory activities of different fractions from the fruits of *P. fortuneana*, and found that 50 and 70% acetone extracts of the fruits of *P. fortuneana* had the highest inhibitory activity against α -glucosidase with the IC₅₀ values of 0.37 and 0.35 mg DM/ml, respectively (Wang et al., 2019).

Ke et al. reported that PFE can alleviate acute nephrotoxicity induced by cadmium chloride (CdCl₂) in rats. The PFE (250 mg/kg) increased the CdCl₂ reduced body weight, antioxidant enzymes in kidney tissue including glutathione (GSH), superoxide dismutase (SOD), catalase (CAT), glutathione peroxidase (GPx), and glutathione peroxidase (GR) in rats. The PFE treatment alleviated inflammation and apoptosis in renal tissue of rats induced by CdCl₂ *via* increasing Bcl-2, NQO1, γ -GCS, HO-1, and Nrf2, and decreasing Bax, Keap-1, and TNF- α in kidney tissue, indicating protective activities of PFE in renal tissues might be achieved through the Nrf2/Keap-1 pathway (Ke et al., 2019). Xu et al. reported that 5% PFE treatment reduced body weight, triglyceride (TG), total cholesterol (TC), and low-density lipoprotein cholesterol (LDL) and increases high-density lipoprotein cholesterol (HDL) in high-fat and high-cholesterol diet-fed rats. The PFE exerted higher LDL receptor (LDLr)-binding activity than single compounds in HepG₂ cells (Xu et al., 2016). The intragastric administration of PFE can significantly shorten the glass slide blood coagulation time of mice. *In vitro*, the PFE fractions can significantly shorten the plasma recalcification time and plasma prothrombin time, and the chloroform fraction of PFE has the most significant effect in PFE (Mei et al., 2001). The PFE can inhibit the water absorption of the small intestine in normal rats, and promote the secretion of bile in rats. The results showed that PFE can increase the solids content in bile, promote the secretion of gastric juice in rats, and improve the activity of pepsin, indicating the PFE has a strong function in improving digestion and invigorating the spleen (Hou et al., 2003a). Peng et al. explored the effects of Se-PFPs on CTX-induced

micronucleus formation in both bone marrow and peripheral blood, and found that Se-PFPs enhanced the activities of SOD and GPx and reduced the activity and expression of cytochrome P450 1A (CYP4501A) in mouse liver, with a dose-dependent manner. This study indicated that the Se-PFPs may provide an alternative strategy for cancer therapy by targeting CYP1A (Peng et al., 2016).

Taheri et al. reported that the oral administration of ethanol extract from the fruits of *P. fortuneana* (ETFP) can reduce the formalin-induced pain, and carrageenan caused paw edema in rats (Taheri et al., 2021). The extracted hydro-alcohol polyphenols of *P. fortuneana* (PPFE) showed excellent antibacterial potentials against both *Staphylococcus aureus* and *Escherichia coli* with the minimum inhibitory concentration (MIC) of 10 and 20 mg/ml (Sun et al., 2019). The PFE intervention could ameliorated intestinal barrier dysfunction in HFD fed rats by protecting structure integrity of intestinal barrier, reducing lactulose/mannitol ratio, inhibiting digestive enzyme activities and upregulating the tight junction proteins, as well as downregulating glucose transporter 2 (GLUT2). Furthermore, the ameliorations in intestinal barrier function were also associated with modulating Intestinal flora (Xu et al., 2019).

Clinical studies

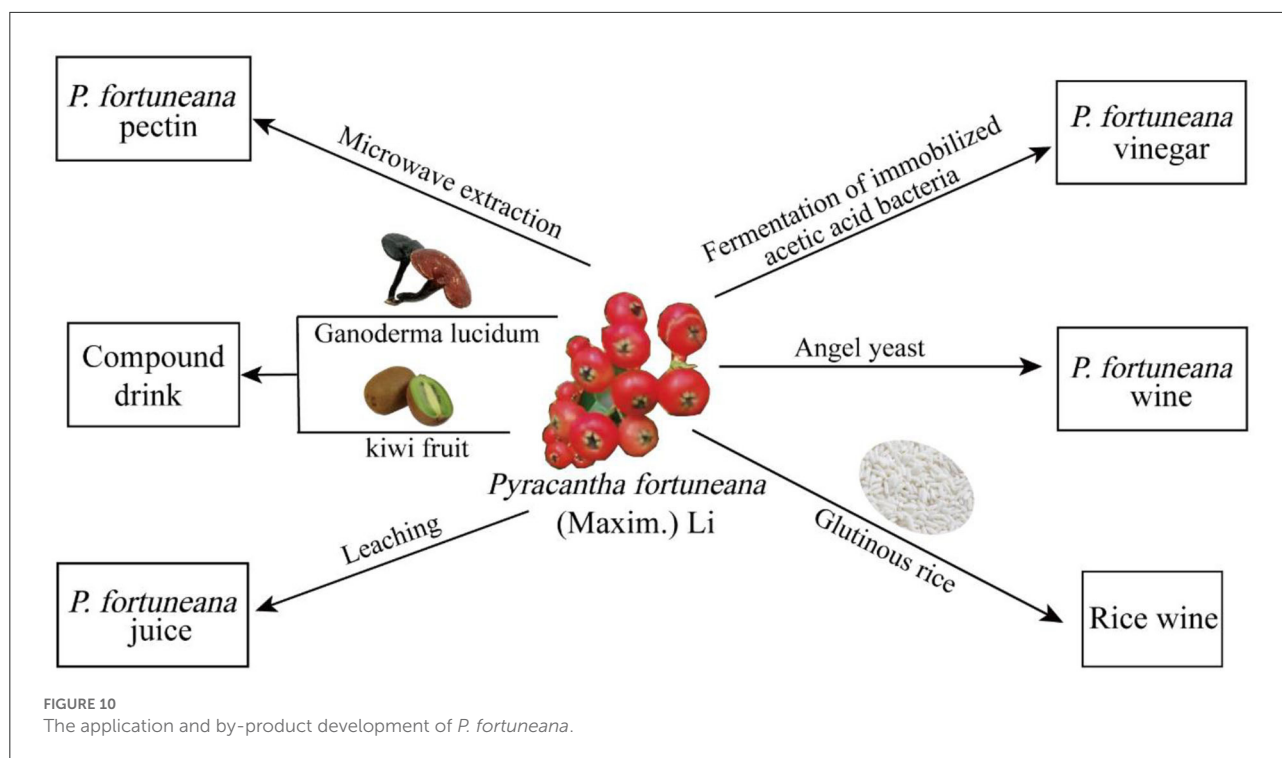
So far, many compounds contained in the *P. fortuneana* have shown certain therapeutic effects in clinical studies. Among the phenolic components, arbutin have been used to treat the uncomplicated urinary tract infections (UTIs) in clinical research; the results showed arbutin may reduce UTI symptoms and reduce antibiotic use for treating UTI (Afshar et al., 2018). Dental caries can occur on crowns and roots of the teeth, and it can appear in early childhood as an aggressive form of tooth decay. Zinc oxide eugenol has been a conventional root canal filling material for pulpectomy of primary teeth since 1930 (Najjar et al., 2019). For overweight men with diabetes, chlorogenic acid (1 g) significantly reduced glucose and insulin concentrations (-0.7 mmol/L and -73 pmol/L, respectively) (van Dijk et al., 2009). Gallic acid can prevent oxidative DNA damage and inflammation in T2D patients, and increase risk of cancer and cardiovascular diseases (Ferk et al., 2018). Ellagic acid has beneficial effects for improving sleep quality and gastrointestinal functions in irritable bowel syndrome patients (Mirzaie et al., 2021). In addition, caffeic acid tablets could be used to treat the primary immune thrombocytopenia with less side effects (Qin et al., 2015). Ferulic acid can improve lipid profile, oxidative stress, oxidized LDL-C, and inflammation in hyperlipidemia patients, and reduce cardiovascular disease risk factors (Bumrungpert et al., 2018). Caffeic acid and ferulic acid can be used for alleviating UV caused skin damage (Saija et al., 2000). Oleanolic acid treatment could reduce serum TC,

TG, and HDLC in hyperlipidemia patients (Luo et al., 2018). Interestingly, the Quercetin Phytosome[®] was reported to be safe drug can be applied to control infection with coronavirus disease 2019 (COVID-19) in the early stages (Di Pierro et al., 2021). A long-term treatment with the mixture of apigenin and epigallocatechin gallate (1:1) can reduce the recurrence rate of colon tumors (Hoensch et al., 2008). Chrysin can reduce the irinotecan (CPT-11) induced diarrhea in cancer patient with metastatic colon cancer (Tobin et al., 2006). Vitexina has radioprotective effects on breast cancer patients receiving Co-60 radiation therapy (Hien et al., 2002). Naringenin can inhibit the inflammation of bronchitis in children, shorten clinical symptoms time, reduce complications incidence, and related adverse reactions (Yao et al., 2021). Rutin can increase dermal density and skin elasticity in women and reduce wrinkles (Choi et al., 2016). The β -eudesmol inhibits sympathetic activity in response to the acute mental stress (Ohara et al., 2018).

Applications and by-products

The fruits of *P. fortuneana* can be prepared into a variety of agricultural and sideline products through fermentation technology (Figure 10). The fruit wine of *P. fortuneana* (FFW) has the unique style with bright red color and full-bodied flavor (Nie et al., 2018; Shi et al., 2020). During the fermentation process of *P. fortuneana* fruit, the changing trends of different chemical components were different. The contents of polysaccharides gradually decreased, whereas the alcohol and free amino acids increased gradually. The contents of flavonoids and polyphenols first increased and then gradually decreased during the fermentation. In addition to its unique flavor, FFW also has a certain antioxidant and α -glucosidase inhibitory activities effect (Cakar et al., 2017; Duan et al., 2020). It is reported that the fermentation broth of the FFW possesses good scavenging effects on free radical of ABTS⁺, and the scavenging effects of FFW would be increased gradually with the prolongation of fermentation time (Jiang et al., 2013). The fruits of *P. fortuneana* can be also fermented with glutinous rice to obtain rice wine. For the rice wine fermented with the fruits of *P. fortuneana* and glutinous rice, the content of sugar, ascorbic acid, total phenols, total flavonoids, and anthocyanins was higher, and the scavenging activity of DPPH[•] and ABTS⁺ was also higher than that of rice wine fermented with glutinous rice alone (Wang et al., 2021).

Pectin is a general term for protopectin and pectate, a hydrophilic vegetable gum that widely exists in the roots, stems, leaves, and fruit cell walls of plants, such as the lacturonic acid, which is a polylinear polysaccharide with an average molecular weight between 2,000 and 40,000 (Thakur et al., 1997). Pectin has good gelling properties, emulsification stability, and high health care effects (Chan et al., 2017). The pectin can be used as a gelling and stabilizing polymer in various food and



specialty products, and therefore pectin is also an excellent matrix for pharmaceutical preparations (Mohnen, 2008). It was reported that the fruits of *P. fortuneana* has abundant pectin, and Chen et al. extracted the pectin with a yield of 83.7% using ultrasonic extraction from the residue of the fruits of *P. fortuneana* after pigment extraction (Chen et al., 2009). Another research by Xiong et al. reported that pectin was extracted from the fruits of *P. fortuneana* by microwave method using dilute hydrochloric acid solution as extractant, and the yield was 7.5% (Xiong et al., 2014).

What is more interesting is, the fruits of *P. fortuneana* can be commonly prepared as drinks such as fruit juice, which possesses good taste and flavor (Cai and Ding, 1996). Besides, it is also reported that the fruit juice of *P. fortuneana* can alleviate liver damage in arsenic poisoned mice by scavenging free radicals (Wei et al., 2006). For the fruit juice drinks, it is reported that original juice content is above 35%, soluble solid content (Brix) is above 8%, total acid is below 0.3% (Chen et al., 2007). Interestingly, the fruits of *P. fortuneana* can be also prepared as lactic acid beverage with abundant nutrition. The protein content of the fruits of *P. fortuneana* lactobacillus beverage obtained by fermentation technology is more than or 1%, and the polysaccharide content is more than or 0.035% (Liu and Wang, 2011). In addition, the fruits of *P. fortuneana* can be also combined with other herbal medicines or fruits to prepare mixed beverages, such as *Ganoderma lucidum* and kiwi fruit (Li et al., 2016a). It is reported that the mixed drink

with *G. lucidum* and the fruits of *P. fortuneana* can enhance the SOD activity (13.9%) and decrease the MDA contents (17.4) in *Drosophila melanogaster*, and extend the lifespan of *D. melanogaster*, compared to the control *D. melanogaster* (Li et al., 2016b). In addition, for the mixed drink of kiwi fruit and the fruits of *P. fortuneana*, the sensory evaluation results showed that the taste and flavor is good, and it is rich in flavonoids, polyphenols, Vc and other functional ingredients (Zhang et al., 2017).

Besides, the fruits of *P. fortuneana* is often used to prepare fruit vinegar, which has lots of biological activities such as anti-fatigue, lipid-lowering, and anti-oxidative stress (Halima et al., 2018; Choi et al., 2020; Kim et al., 2020). For the fruit vinegar of *P. fortuneana* fermented by immobilized acetic bacteria, the contents of total acid (calculated as acetic acid) and total sugar (calculated as glucose) of were 4.9 g/100 ml and 3.6 g/100 ml, respectively (Li, 2012). In addition, the acetic acid content of the fruit vinegar of *P. fortuneana* fermented by acetic shake flask can achieve the high value of 60.3 mg/ml (Zhou et al., 2008). The average content of γ -aminobutyric acid in the compound fruit vinegar of *P. fortuneana* and sprouted brown rice is 331.2 mg/L, and it also contains nine amino acids necessary for the human body, including leucine (32.42 mg/100 ml), isoleucine (15.46 mg/100 ml), lysine (3.91 mg/100 ml), methionine (8.25 mg/100 ml), phenylalanine (21.82 mg/100 ml), threonine (14.79 mg/100 ml), tryptophan (2.95 mg/100 ml), valine (923.60 mg/100 ml), and histidine (11.06

mg/100 ml) (Yuan et al., 2006). Furthermore, the food industry also often uses fruit vinegar to improve the bioavailability of fruit by-products (Luzón-Quintana et al., 2021). The fruit vinegar of *P. fortuneana* is rich in natural and harmonious aroma, sweet and sour taste, and is a health care fruit vinegar with nutrition (Gao, 2012).

Non-food applications

Owing to the continuous improvement of people's living environment and the gradual improvement of urban landscaping grades, people pay increasing attention to the color beauty of landscaping plants. Color plants can achieve a harmonious unity between man and nature, which is a manifestation of people's longing for colorful plants. Also, *P. fortuneana* has strong adaptability and is easy to prune. It can be made into hedges, planted in green belts on roads, used in lawn arrangements, and can be also used for potted plants (Zhang and Li, 2020). For example, leaves of the *P. fortuneana* "Harlequin" are white, with good ornamental and ecological properties, and are commonly used in garden landscaping (Xu, 2017). Furthermore, *P. fortuneana* leaves can absorb and retain atmospheric particles and are also important for remediating environmental pollution (Sun et al., 2018).

Stony desertification refers to the destruction of surface vegetation by human activities under the tropical and subtropical humid and semi-humid climatic conditions and the natural background of extremely developed karst. Stony desertification resulted in serious soil loss and large areas of exposed bedrock or karst (Zhang et al., 2018). Moreover, *P. fortuneana* has strong adaptability and vitality and can be propagated by cuttings, sowing, and layering, and its fruit ripening in winter also maintains species diversity. In addition, it has many functions such as edible, medicinal, feed, ornamental, and soil and water conservation, it consequently has high development and utilization value and broad market prospects. It is reported that *P. fortuneana* is the preferred species for controlling rocky desertification, and it should be developed and utilized rationally (He, 2014; Rojas et al., 2019). Although *P. fortuneana* has a tenacious vitality and can adapt to various environments, more attention should be also paid to the protection of diseases, especially anthracnose (Peng and Xie, 2020). In addition, further works should be also paid to pests such as pear crown stink bug, boat caterpillar, and cinnabar spider mite, as well as diseases such as powdery mildew, leaf spot and rust (Pu, 2014).

The endophytic fungi isolated from *P. fortuneana* can produce anti-bacterial effects on nine kinds of crop pathogenic fungi, such as wheat root rot, wheat scab, tomato early blight, etc. It has the characteristics of remarkable anti-bacterial effect with broad anti-bacterial spectrum and can be developed as an effective pesticide of microbial origin (Tian and Chen, 2012).

Aflatoxin is a mycotoxin produced by *Aspergillus* and is present in various foods. Eating foods contaminated with aflatoxin can cause adverse health effects (Saha Turna and Wu, 2019). The biomass in the aqueous extracts of *P. fortuneana* has an adsorption effect on aflatoxins (Zavala-Franco et al., 2018). The adsorption mechanism is mainly regarding the electrostatic interaction between the negatively charged functional groups and the positively charged aflatoxin molecules. Further studies showed that hydroxyl, amino, carboxyl, amide, phosphate, and ketone play important roles in the adsorption process, which can be used as a substitute for traditional aflatoxin removal (Ramales-Valderrama et al., 2016; Méndez-Albores et al., 2020).

Besides, it is reported that *P. fortuneana* extract has high bioadsorption performance for the dye methylene blue at the pH around 6, and *P. fortuneana* can be used as a natural, economical, abundant, and effective bio adsorbent in wastewater treatment (Akar et al., 2009). Alkyl benzyl dimethyl ammonium chloride (ABDAC) modification significantly increased the biosorption yield of *P. fortuneana* to 97.27%, which was 3.88 times higher than that of natural biomass. The prepared biosorbent was effectively used for the decolorization of reactive Red 45 contaminated solutions after the optimization of biosorption conditions (Akar et al., 2013). Next, modification of the biosorbent obtained from *P. fortuneana* with anionic surfactants was successfully employed for decolorization of methyl violet (MV)-contaminated solutions (Akar et al., 2014).

Toxicity profiles

From the ancient times to the present, the *P. fortuneana* is commonly considered as a safe nutritious plant without toxicity, and there are few reports regarding the side effects of this plant so far. In 1992, Wang et al. evaluated the oral toxicity of the fruit juice from *P. fortuneana* (containing 60% solids) in mice, and the results showed that the median lethal dose (LD₅₀) value was higher than 28 g/kg, indicating that the toxicological classification of the fruit juice of *P. fortuneana* could belong to "non-toxic" (Wang et al., 1992). However, it is reported that ursolic acid, which is a compound reported in the fruits of *P. fortuneana*, would lead to transient relief of metabolic syndrome, weight loss, waist circumference and fasting blood glucose, and increased insulin sensitivity (Ramírez-Rodríguez et al., 2017).

Conclusion

In conclusion, the fruits, leaves, and roots of *P. fortuneana* are rich in bioactive components, mainly including proanthocyanidins, polyphenols, natural pigments and polysaccharides, etc. The previous *in vitro* and *in vivo* studies

have revealed that extracts or compounds in *P. fortuneana* have potential biological and pharmacological properties, such as antioxidant, antitumor, hypolipidemic, gut microbiota regulation, and immunomodulatory activities. However, the key problem in the products development of *P. fortuneana* is that the fruit is astringent in taste and small in size, which leads to the low acceptance of this fruit and greatly affects the industrialization of its related products. Therefore, more research could be carried out to the appropriate increase of production of the fruits of *P. fortuneana*, and solve the astringent taste of the fruit. Although researchers have successively developed a series of products such as fruit juice, beverages, fruit vinegar, and health care wine, these products mentioned above are still in the relatively primary development stage, and no large-scale industrial production has been seen (Teng et al., 2017; Zhou et al., 2018). Consequently, further works should be devoted to development of more high-end products of this plant, such as clinical drugs, functional foods, and biopesticide, etc. Furthermore, the available current quality controlling of the fruits of *P. fortuneana* is lacking, especially for the medicinal use, which seriously limited the development of the high-end products of the fruits of *P. fortuneana*. So, the quality controlling standard of the fruits of *P. fortuneana* for food and medicinal use should be constructed based on the studies of characteristic bio-active compounds of this plant. Lastly, although lots of the activities of the fruit have been reported, most of them are studied superficially, and most or the previous studies mainly focused on the preliminary efficacy without a systemic research on molecular mechanisms, targets, and target organs. Thus, the future investigations should be devoted to explore the profound mechanisms of the extracts/compounds in the fruit of this plant. This study systematically summarized the research trends of the *P. fortuneana* and its phytochemical compositions, nutritional values, pharmacological effects, and health benefits of its extracts/monomers, which would be beneficial for the future development of this medicinal plant as functional food or drugs.

References

- Afshar, K., Fleischmann, N., Schmiemann, G., Bleidorn, J., Hummers-Pradier, E., Friede, T., et al. (2018). Reducing antibiotic use for uncomplicated urinary tract infection in general practice by treatment with uva-ursi (REGATTA) - a double-blind, randomized, controlled comparative effectiveness trial. *BMC Complement. Altern. Med.* 18, 203. doi: 10.1186/s12906-018-2266-x
- Akar, S. T., Sayin, F., Turkyilmaz, S., and Akar, T. (2014). Multivariate optimization of the decolorization process by surface modified biomaterial: Box-Behnken design and mechanism analysis. *Environ. Sci. Pollut. Res. Int.* 21, 13055–13068. doi: 10.1007/s11356-014-3245-5
- Akar, T., Anilan, B., Gorgulu, A., and Akar, S. T. (2009). Assessment of cationic dye biosorption characteristics of untreated and non-conventional biomass: *Pyracantha coccinea* berries. *J Hazard Mater.* 168, 1302–1309. doi: 10.1016/j.jhazmat.2009.03.011
- Akar, T., Ozkara, E., Celik, S., Turkyilmaz, S., and Akar, S. T. (2013). Chemical modification of a plant origin biomass using cationic surfactant ABDAC and

Author contributions

WP, XP, and CW organized and supervised this study. LW wrote the manuscript and prepared tables and figures. RL wrote and contributed to the revision of the manuscript. QZ contributed to the check of tables. TT performed the revisions of figures. TZ and QR participated in the revision of the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

Author XP is employed by Chengdu Medical and Health Investment Group Co. Ltd.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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the biosorptive decolorization of RR45 containing solutions. *Colloids Surf. B Biointerfaces* 101, 307–314. doi: 10.1016/j.colsurfb.2012.06.016

Belwal, T., Pandey, A., Bhatt, I. D., Rawal, R. S., and Luo, Z. (2019). Trends of polyphenolics and anthocyanins accumulation along ripening stages of wild edible fruits of Indian Himalayan region. *Sci. Rep.* 9, 5894. doi: 10.1038/s41598-019-42270-2

Bumrungpert, A., Lilitchan, S., Tuntipipat, S., Tirawanchai, N., and Komindr, S. (2018). Ferulic acid supplementation improves lipid profiles, oxidative stress, and inflammatory status in hyperlipidemic subjects: a randomized, double-blind, placebo-controlled clinical trial. *Nutrients*. 10, 713. doi: 10.3390/nu10060713

Cai, J. T., and Ding, Z. H. (1996). The processing technology of the *Pyracantha* fruit juice drinks. *Sci. Technol. Food Indu.* 2, 40–42.

Caçar, U., Grozđanic, N., Petrovic, A., Pejcin, B., Nastasijevic, B., Markovic, B., et al. (2017). Fruit wines inhibitory activity against α -glucosidase. *Curr. Pharm. Biotechnol.* 18, 1264–1272. doi: 10.2174/1389201019666180410112439

- Chan, S. Y., Choo, W. S., Young, D. J., and Loh, X. J. (2017). Pectin as a rheology modifier: origin, structure, commercial production and rheology. *Carbohydr. Polym.* 161, 118–139. doi: 10.1016/j.carbpol.2016.12.033
- Chen, K., and Tan, Q. Q. (2021). Analysis of nutrient components of *Pyracantha fruit*. *Chin. Food Saf. Mag.* 15, 94–96. doi: 10.16043/j.cnki.cfs.2021.15.057
- Chen, Q., Li, Z., and Sun, M. (2011). Research advance in *Pyracantha rosa* L. of rosaceae. *Food Eng.* 3, 11–13. doi: 10.3969/j.issn.1673-6044.2011.03.006
- Chen, Y., Huang, Z. L., Jiang, L. H., Xiong, Y. F., Wen, Z. Y., and Zhu, H. F. (2009). Studies on extraction of pectin in *Pyracantha fortuneana* with ultrasonic wave. *China Food Addit.* 6, 54–58. doi: 10.3969/j.issn.1006-2513.2009.06.008
- Chen, Y., Lu, Z. M., and Li, Z. X. (2007). Study on processing and HACCP controlling of *Pyracantha fortuneana* beverage. *Food Sci.* 8, 598–601. doi: 10.3321/j.issn.1002-6630.2007.08.152
- Chhikara, N., Kushwaha, K., Sharma, P., Gat, Y., and Panghal, A. (2019). Bioactive compounds of beetroot and utilization in food processing industry: a critical review. *Food Chem.* 272, 192–200. doi: 10.1016/j.foodchem.2018.08.022
- Choi, D., Kang, W., Park, S., Son, B., and Park, T. (2021). β -Ionone attenuates dexamethasone-induced suppression of collagen and hyaluronic acid synthesis in human dermal fibroblasts. *Biomolecules* 11, 619. doi: 10.3390/biom11050619
- Choi, J. H., Kim, M. K., Yeo, S. H., and Kim, S. (2020). Short-term *Cudrania tricuspidata* fruit vinegar administration attenuates obesity in high-fat diet-fed mice by improving fat accumulation and metabolic parameters. *Sci Rep.* 10, 21102. doi: 10.1038/s41598-020-78166-9
- Choi, S. J., Lee, S. N., Kim, K., Joo da, H., Shin, S., Lee, J., et al. (2016). Biological effects of rutin on skin aging. *Int J Mol Med.* 38, 357–363. doi: 10.3892/ijmm.2016.2604
- Chu, H. Y., Wei, J. H., and Li, Y. (2015). Determining trace elements in *Gleditsia sinensis* Lam. Stings and *Pyracantha fortuneana* with atomic absorption spectrometry. *Hubei Agric. Sci.* 54, 171–174. doi: 10.14088/j.cnki.issn0439-8114.2015.01.044
- Dai, Y., He, X. J., Zhou, G. X., Kurihara, H., Ye, W. C., and Yao, X. S. (2008). Acylphloroglucinol glycosides from the fruits of *Pyracantha fortuneana*. *J. Asian Nat. Prod. Res.* 10, 111–117. doi: 10.1080/10286020601106018
- Dai, Y., Zhou, G. X., Kurihara, H., Ye, W. C., and Yao, X. S. (2006). Biphenyl glycosides from the fruit of *Pyracantha fortuneana*. *J. Nat. Prod.* 69, 1022–1024. doi: 10.1021/mp0600853
- Dai, Y., Zhou, G. X., Kurihara, H., Ye, W. C., and Yao, X. S. (2009). A biphenyl glycoside from *Pyracantha fortuneana*. *Nat. Prod. Res.* 23, 1163–1167. doi: 10.1080/14786410802213985
- Di Piero, F., Derosa, G., Maffioli, P., Bertuccioli, A., Togni, S., Riva, A., et al. (2021). Possible therapeutic effects of adjuvant quercetin supplementation against early-stage COVID-19 infection: a prospective, randomized, controlled, and open-label study. *Int. J. Gen. Med.* 14, 2359–2366. doi: 10.2147/IJGM.S318720
- Dong, L. S. (2002). Analysis of phospholipids in *Pyracantha fortuneana* fruit. *Acta Nutr. Sin.* 2, 209–211. doi: 10.13325/j.cnki.acta.nutr.sin.2002.02.027
- Duan, Q. X., Li, D. J., Duan, Z. H., Chen, Y., Tang, M. L., and Wu, L. M. (2020). Study on changes of antioxidant activity of red heart Pitaya wines during storage. *Food Res. Dev.* 41, 43–49. doi: 10.12161/j.issn.1005-6521.2020.24.008
- Editorial Committee of Flora of China and Chinese Academy of Sciences (1973). *Pyracantha fortuneana* (Maxim.) Li. *Flora China* 36, 180.
- Farkhondeh, T., Samarhandian, S., and Roshanravan, B. (2019). Impact of chrysin on the molecular mechanisms underlying diabetic complications. *J. Cell Physiol.* 234, 17144–17158. doi: 10.1002/jcp.28488
- Ferk, F., Kundi, M., Brath, H., Szekeres, T., Al-Serori, H., Mišik, M., et al. (2018). Gallic acid improves health-associated biochemical parameters and prevents oxidative damage of DNA in type 2 diabetes patients: results of a placebo-controlled pilot study. *Mol. Nutr. Food Res.* 62, 1–30. doi: 10.1002/mnfr.201700482
- Fico, G., Billam, A. R., Morelli, I. I., and Tomè, F. (2000). Flavonoid distribution in *Pyracantha coccinea* plants at different growth phases. *Biochem. Syst. Ecol.* 28, 673–678. doi: 10.1016/S0305-1978(99)00109-X
- Fu, Y. (2014). Analysis and evaluation on nutritional components of fruit of 4 germplasm in *Pyracantha fortuneana*. *J. Anhui Agric. Sci.* 42, 2. doi: 10.13989/j.cnki.0517-6611.2014.06.083
- Fuller, S., Beck, E., Salman, H., and Tapsell, L. (2016). New horizons for the study of dietary fiber and health: a review. *Plant Foods Hum. Nutr.* 71, 1–12. doi: 10.1007/s11130-016-0529-6
- Gan, X. H., Zhao, Y., Zhou, X., Zhao, C., and Liang, Z. Y. (2012). Comparison of the contents of quercetin in various medicinal parts of *Pyracantha fortuneana*. *Chin. J. Exp. Trad. Med. Formulae.* 18, 100–102. doi: 10.13422/j.cnki.syfjx.2012.11.036
- Gao, L. (2012). Application of immobilized technology in the fermentation process of *Pyracantha fortuneana* vinegar. *Storage Process.* 12, 35–38. doi: 10.3969/j.issn.1009-6221.2012.05.008
- Gao, W., Wang, C., Yu, L., Sheng, T., Wu, Z., Wang, X., et al. (2019). Chlorogenic acid attenuates dextran sodium sulfate-induced ulcerative colitis in mice through MAPK/ERK/JNK pathway. *Biomed. Res. Int.* 2019, 6769789. doi: 10.1155/2019/6769789
- Gao, Y. L. (2020). *Pyracantha fortuneana*. *Flowers* 9, 47. Available online at: <https://kns.cnki.net/kcms/detail/detail.aspx?FileName=HUU202009019&DbName=CJFN2020>
- Gao, Z. Y., Liu, S. L., Zhang, H. L., and Xie, H. X. (2019). Determination of contents of metal elements in *Pyracantha fortuneana* fruit by flame atomic absorption spectrometry. *Chem. Bioeng.* 36, 65–68. doi: 10.3969/j.issn.1672-5425.2019.04.015
- Ge, L. N., Han, X., Ren, K. K., Zhang, P., Peng, Y. Y., and Bi, S. F. (2014). GC-MS analysis on chemical constituents and antioxidant activity of volatile oil from *Pyracantha fortuneana* flowers. *Bull. Bot. Res.* 34, 276–281. doi: 10.7525/j.issn.1673-5102.2014.02.022
- Ghanim, A. M. H., Younis, N. S., and Metwally, H. A. (2021). Vanillin augments liver regeneration effectively in thioacetamide induced liver fibrosis rat model. *Life Sci.* 286, 120036. doi: 10.1016/j.lfs.2021.120036
- González-Burgos, E., and Gómez-Serranillos, M. P. (2012). Terpene compounds in nature: a review of their potential antioxidant activity. *Curr. Med. Chem.* 19, 5319–5341. doi: 10.2174/092986712803833335
- Halima, B. H., Sonia, G., Sarra, K., Houda, B. J., Fethi, B. S., and Abdallah, A. (2018). Apple cider vinegar attenuates oxidative stress and reduces the risk of obesity in high-fat-fed male wistar rats. *J. Med. Food* 21, 70–80. doi: 10.1089/jmf.2017.0039
- Han, L., Wu, Y. M., Wang, K. T., Wang, Z. D., Tang, H. L., and Gao, Y. J. (2015). Study on the monosaccharide compositions, physico-properties and preparation technology of soluble dietary fiber by enzymatic method from *Pyracantha fortuneana*. *Sci. Technol. Food Ind.* 36, 215–219. doi: 10.13386/j.issn1002-0306.2015.17.035
- Han, W. Q., and Zhang, G. F. (2019). Study on nutritional components and antioxidant activity of total flavonoids in *Pyracantha fruit*. *Agric Sci.* 9, 399–404. doi: 10.12677/HJAS.2019.96059
- He, R. F. (2014). Development and utilization of *Pyracantha fortuneana* in rocky desertification control. *Agric Sci.* 34, 128–133. doi: 10.3969/j.issn.1671-962X.2014.06.098
- He, R. R., Li, W. X., Li, Y. F., and Li, Y. B. (2011). Whitening effects of fruit extract of *Pyracantha fortuneana*. *Chin. J. Exp. Tradit. Med. Formul.* 17, 184–188. doi: 10.13422/j.cnki.syfjx.2011.02.052
- He, Y. F., Huang, Y. B., Li, Y. M., Yang, M., Yin, C. R., Liao, Y. Q., et al. (2018). Simultaneous determination of multiple trace elements in *Pyracantha fortuneana* by ICP-MS. *J. A. Agric. Sci.* 46, 177–178+218. doi: 10.13989/j.cnki.0517-6611.2018.13.053
- He, Y. F., Yang, S. J., Zhang, W., Zhou, Y., Duan, Y. J., and Wu, J. W. (2019). Determination of the contents of earth elements in different tissues of *Pyracantha fortuneana*. *Sci. Tech. Food Ind.* 40, 257–265. doi: 10.13386/j.issn1002-0306.2019.04.042
- Hien, T. V., Huong, N. B., Hung, P. M., and Duc, N. B. (2002). Radioprotective effects of vitexina for breast cancer patients undergoing radiotherapy with cobalt-60. *Integr. Cancer Ther.* 1, 38–34; discussion 42–33. doi: 10.1177/1534735402001001003
- Hoensch, H., Groh, B., Edler, L., and Kirch, W. (2008). Prospective cohort comparison of flavonoid treatment in patients with resected colorectal cancer to prevent recurrence. *World J. Gastroenterol.* 14, 2187–2193. doi: 10.3748/wjg.14.2187
- Hou, J. J., Liu, X. L., Wei, W. K., and Wu, M. G. (2003a). Animal test on the efficacy of pyracantha to dissipate food and invigorate the spleen. *Hubei Agric. Sci.* 84–86. doi: 10.3969/j.issn.0439-8114.2003.04.035
- Hou, J. J., Wei, W. K., Huang, H., and Wu, M. G. (2003b). Antioxidation effects of pyracantha on aging mice model induced by overdose of D-galactose. *Chin. J. Public Health* 19, 944–945. doi: 10.11847/zgggws2003-19-08-31
- Hou, J. J., Wei, W. K., Xue, H., and Zhang, H. (2002). Research progress of wild plant *Pyracantha fortuneana*. *J. Hubei Minzu Univ.* 15–18. doi: 10.3969/j.issn.1008-8423.2002.01.005
- Huang, P. A. (2014). Determination of trace elements in *Pyracantha fortuneana*. *Edu. Teach. Forum* 31, 156–157. doi: 10.3969/j.issn.1674-9324.2014.31.107

- Huang, R., and Fu, X. H. (2014). Advances on research of functional composition of *Pyracantha fortuneana*. *Chin. Wild Plant Res.* 33, 37–41. doi: 10.3969/j.issn.1006-9690.2014.05.011
- Huang, Y. C., Yang, F., Xie, Q. R., and Duan, Y. F. (2007a). Study on physicochemical property of PP-A3 from water-soluble *Pyracantha fortuneana* polysaccharides. *Food Res. Dev.* 8, 75–79. doi: 10.3969/j.issn.1005-6521.2007.08.023
- Huang, Y. C., Yang, F., Xie, Q. R., and Duan, Y. F. (2007b). Study on physicochemical property of PP-A2 from water-soluble *Pyracantha fortuneana* polysaccharides. *Food Sci. Technol.* 6, 116–119. doi: 10.13684/j.cnki.spkj.2007.06.037
- Humbeck, K., Römer, S., and Senger, H. (1989). Evidence for an essential role of carotenoids in the assembly of an active photosystem II. *Planta*. 179, 242–50. doi: 10.1007/bf00393695
- Jiang, C. L., Zhuang, Y., Zhu, D. G., Cheng, C., and Li, W. (2013). Changes of chemical contents and their antioxidant activities during wine processing of *Pyracantha fortuneana* (Maxim.) Li. *China Brew.* 32, 80–83. doi: 10.3969/j.issn.0254-5071.2013.08.019
- Jiang, L. H., Xiong, Y. F., Li, X., Wen, Z. Y., and Liu, W. (2007). Research progress on active ingredients of wild *Pyracantha fortuneana*. *Chin Wild Plant Res.* 26, 8–10. doi: 10.3969/j.issn.1006-9690.2007.02.003
- Jo, H., Cha, B., Kim, H., Brito, S., Kwak, B. M., Kim, S. T., et al. (2021). α -Pinene enhances the anticancer activity of natural killer cells via ERK/AKT pathway. *Int. J. Mol. Sci.* 22, 656. doi: 10.3390/ijms22020656
- Johnson, W., Bergfeld, W. F., Belsito, D. V., Hill, R. A., Klaassen, C. D., Liebler, D. C., et al. (2017). Safety assessment of benzyl alcohol, benzoic acid and its salts, and benzyl benzoate. *Int. J. Toxicol.* 36 (3 Suppl), 5s–30s. doi: 10.1177/1091581817728996
- Kang, W., Choi, D., and Park, T. (2020). Decanal protects against UVB-induced photoaging in human dermal fibroblasts via the cAMP pathway. *Nutrients* 12, 1214. doi: 10.3390/nu12051214
- Kashiwadani, H., Higa, Y., Sugimura, M., and Kuwaki, T. (2021). Linalool odor-induced analgesia is triggered by TRPA1-independent pathway in mice. *Behav. Brain Funct.* 17, 3. doi: 10.1186/s12993-021-00176-y
- Ke, Y., Yu, K., Zeng, W., and Lian, G. (2019). Protective roles of *Pyracantha fortuneana* extract on acute renal toxicity induced by cadmium chloride in rats. *Acta Cir. Bras.* 34, e201900706. doi: 10.1590/s0102-865020190070000006
- Keser, S. (2014). Antiradical activities and phytochemical compounds of firethorn (*Pyracantha coccinea*) fruit extracts. *Nat. Prod. Res.* 28, 1789–1794. doi: 10.1080/14786419.2014.942304
- Kim, J. H., Cho, H. D., Won, Y. S., Hong, S. M., Moon, K. D., and Seo, K. I. (2020). Anti-fatigue effect of *Prunus mume* vinegar in high-intensity exercised rats. *Nutrients* 12, 1205. doi: 10.3390/nu12051205
- Laganà, P., Coniglio, M. A., Fiorino, M., Delgado, A. M., Chammen, N., Issaoui, M., et al. (2020). Phenolic substances in foods and anticarcinogenic properties: a public health perspective. *J. AOAC Int.* 103, 935–939. doi: 10.1093/jaoacint/qs028
- Li, J. X., Huang, S. E., and Liang, X. Z. (2012). Progress in research and development of *Pyracantha fortuneana*. *Food. Mchnr.* 28, 260–263. doi: 10.3969/j.issn.1003-0658.2012.06.005
- Li, J. Z., Wang, D. Z., and Huang, Y. Q. (2016a). Compound health beverage of *Ganoderma lucidum* and *Pyracantha fortuneana* developed by response surface method. *Sci. Technol. Food Ind.* 37, 238–242. doi: 10.13386/j.issn1002-0306.2016.21.037
- Li, J. Z., Wang, D. Z., and Huang, Y. Q. (2016b). Effect of *Pyracantha crenulata*-*Ganoderma lucidum* beverage on the growth and antioxidant properties of drosophila melanogaster. *Acta Edulis Fungi* 23, 40–43. doi: 10.16488/j.cnki.1005-9873.2016.04.008
- Li, P. X., Mao, G. H., Zhao, T., Zhou, Y., Ren, Y. N., Bai, S. Q., et al. (2013). Extraction and antioxidant activity of red pigments from *Pyracantha fortuneana*. *Food Sci.* 34, 116–119. doi: 10.7506/spkx1002-6630-201317026
- Li, R. L., Zhang, Q., Liu, J., Sun, J. Y., He, L. Y., Duan, H. X., et al. (2020). Hydroxy- α -sanshool possesses protective potentials on H₂O₂-stimulated PC₁₂ cells by suppression of oxidative stress-induced apoptosis through regulation of PI3K/Akt signal pathway. *Oxid. Med. Cell Longev.* 2020, 3481758. doi: 10.1155/2020/3481758
- Li, W., and Chen, C. (2013). The antioxidation effect *in vitro* of flavonoides from different *Pyracantha fortuneana* fruits. *J. Hubei Minzu Univ.* 31, 382–385. doi: 10.3969/j.issn.1008-8423.2013.04.005
- Li, W., Cheng, C., Zhang, Y. T., Yan, L., and Mo, K. J. (2008). Clustering analysis of functional components in different *Pyracantha fortuneana* (Maxim.) Li. fruits. *Food Sci.* 207–210. doi: 10.3321/j.issn:1002-6630.2008.09.043
- Li, W., Tian, C., Wang, M., and Cheng, C. (2013). Extraction optimization and its antioxidant activities of flavonoides from *Pyracantha fortuneana* (Maxim.) Li. fruits. *J. Hubei Minzu Univ.* 31, 145–148. doi: 10.3969/j.issn.1008-8423.2013.02.007
- Li, W. F., Ma, H. H., Yuan, S., and Zhang, X. F. (2021). Production of pyracantha polysaccharide-iron(III) complex and its biologic activity. *Molecules* 26, 1949. doi: 10.3390/molecules26071949
- Li, Y. H. (2012). Study on the technology of immobilized acetobacter for brewing *Pyracantha vinegar*. *J. Shaanxi Inst. Edu.* 28, 90–94. Available online at: [https://kns.cnki.net/kcms/detail/detail.aspx?FileName=\\$SHA201203020&DbName=CJFQ2012](https://kns.cnki.net/kcms/detail/detail.aspx?FileName=$SHA201203020&DbName=CJFQ2012)
- Lin, R. D., Chen, M. C., Liu, Y. L., Lin, Y. T., Lu, M. K., Hsu, F. L., et al. (2015). New whitening constituents from Taiwan-native *Pyracantha koidzumii*: structures and tyrosinase inhibitory analysis in human epidermal melanocytes. *Int. J. Mol. Sci.* 16, 28598–28613. doi: 10.3390/ijms161226115
- Liu, J., Xu, Y. F., Lu, H. C., Wang, H. J., Gui, J., Chen, X. Z., et al. (2015). Study on the stability of proanthocyanidins from *Pyracantha fortuneana* fruit. *Food Res. Dev.* 36, 29–32. doi: 10.3969/j.issn.1005-6521.2015.07.008
- Liu, M. H., and Wang, D. H. (2011). Development of *Pyracantha fortuneana* lactobacillus beverage. *China Brew.* 6, 92–196. doi: 10.3969/j.issn.0254-5071.2011.06.055
- Luo, B. F., Wang, J. N., Huang, Y. M., and Huang, Z. L. (2014). Advances in the wild *Pyracantha fortuneana* research. *China Brew.* 33, 1–4. doi: 10.3969/j.issn.0254-5071.2014.02.001.y
- Luo, H. Q., Shen, J., Chen, C. P., Ma, X., Lin, C., Ouyang, Q., et al. (2018). Lipid-lowering effects of oleonic acid in hyperlipidemic patients. *Chin. J. Nat. Med.* 16, 339–346. doi: 10.1016/S1875-5364(18)30065-7
- Luo, X., Li, T. J., Bao, Y. R., Wang, S., and Meng, X. S. (2021). Extraction of active components from *Fructus aurantii* for colon cancer based on HT-29 cells. *Cent. South Pharm.* 19, 455–459. doi: 10.7539/j.issn.1672-2981.2021.03.015
- Luzón-Quintana, L. M., Castro, R., and Durán-Guerrero, E. (2021). Biotechnological processes in fruit vinegar production. *Foods* 10, 945. doi: 10.3390/foods10050945
- Ma, W., Zhao, L., Zhao, W., and Xie, Y. (2019). (E)-2-Hexenal, as a potential natural antifungal compound, inhibits *aspergillus flavus* spore germination by disrupting mitochondrial energy metabolism. *J. Agric. Food Chem.* 67, 1138–1145. doi: 10.1021/acs.jafc.8b06367
- Mattila, P., and Kumpulainen, J. (2002). Determination of free and total phenolic acids in plant-derived foods by HPLC with diode-array detection. *J. Agric. Food Chem.* 50, 3660–3667. doi: 10.1021/jf020028p
- Mei, X. G., Wan, G. H., Zhou, Z. Q., Chang, J. L., and Wu, H. L. (2001). Effects of *Pyracantha fortuneana* extract on blood coagulation. *J. Chin. Med. Mater.* 24, 874–876. doi: 10.3321/j.issn:1001-4454.2001.12.014
- Méndez-Alboreas, A., Escobedo-González, R., Aceves-Hernández, J. M., García-Casillas, P., Nicolás-Vázquez, M. I., and Miranda-Ruvalcaba, R. (2020). A theoretical study of the adsorption process of aflatoxins using *Pyracantha koidzumii* (Hayata) rehd. biomass. *Toxins* 12, 283. doi: 10.3390/toxins12050283
- Mertz, W. (1981). The essential trace elements. *Science*. 213, 1332–1338. doi: 10.1126/science.7022654
- Mirzaie, Z., Bastani, A., Hesami, S., Pouryousefi, E., Kavianpour, M., and Haghighian, H. K. (2021). Improving effect of ellagic acid on sleep quality and gastrointestinal symptoms in patient with irritable bowel syndrome: randomized double-blind clinical trial. *Turk. J. Gastroenterol.* 32, 937–944. doi: 10.5152/tjg.2021.20344
- Mohnen, D. (2008). Pectin structure and biosynthesis. *Curr. Opin. Plant Biol.* 11, 266–277. doi: 10.1016/j.pbi.2008.03.006
- Mu, M., Zuo, S., Wu, R. M., Deng, K. S., Lu, S., Zhu, J. J., et al. (2018). Ferulic acid attenuates liver fibrosis and hepatic stellate cell activation via inhibition of TGF- β /Smad signaling pathway. *Drug Des. Dev. Ther.* 12, 4107–4115. doi: 10.2147/DDDT.S186726
- Nai, G. R. Y., Li, P. H., Peng, Z. S., Li, S. Q., Peng, R., and Zhao, H. (2020). Research progress of *Pyracantha fortuneana*. *Sichuan Agric. Sci. Tech.* 10, 20–22. Available online at: [https://kns.cnki.net/kcms/detail/detail.aspx?FileName=\\$SSNYK202010007&DbName=\\$CJFQ2020](https://kns.cnki.net/kcms/detail/detail.aspx?FileName=$SSNYK202010007&DbName=$CJFQ2020)
- Najjar, R. S., Alamoudi, N. M., El-Housseiny, A. A., Al Tuwiriq, A. A., and Sabbagh, H. J. (2019). A comparison of calcium hydroxide/iodoform paste and zinc oxide eugenol as root filling materials for pulpctomy in primary teeth: a systematic review and meta-analysis. *Clin. Exp. Dent. Res.* 5, 294–310. doi: 10.1002/cre2.173
- Nie, Z. L., Xu, Y. Q., Liu, J., and Wang, J. H. (2018). Study on the brewing method of wild *Pyracantha fortuneana* fruit wine. *Food Res. Dev.* 39, 104–108. doi: 10.3969/j.issn.1005-6521.2018.24.017

- Ohara, K., Misaizu, A., Kaneko, Y., Fukuda, T., Miyake, M., Miura, Y., et al. (2018). β -Eudesmol, an oxygenized sesquiterpene, reduces the increase in saliva 3-methoxy-4-hydroxyphenylglycol after the "trier social stress test" in healthy humans: a randomized, double-blind, placebo-controlled cross-over study. *Nutrients* 11, 9. doi: 10.3390/nu11010009
- Otsuka, H., Fujioka, S., Komiya, T., Goto, M., Hiramatsu, Y., and Fujimura, H. (1981). Studies on anti-inflammatory agents. V. A new anti-inflammatory constituent of *Pyracantha crenulata* roem. *Chem. Pharm. Bull.* 9, 3099–3104. doi: 10.1248/cpb.29.3099
- Peng, F., Guo, X., Li, Z., Li, C., Wang, C., Lv, W., et al. (2016). Antimutagenic effects of selenium-enriched polysaccharides from *Pyracantha fortuneana* through suppression of cytochrome P450 1A subfamily in the mouse liver. *Molecules* 21, 1731. doi: 10.3390/molecules21121731
- Peng, W., Chen, Y., Tumilty, S., Liu, L., Luo, L., Yin, H., et al. (2022). Paconiflorin is a promising natural monomer for neurodegenerative diseases via modulation of Ca and ROS homeostasis. *Curr. Opin. Pharmacol.* 62, 97–102. doi: 10.1016/j.coph.2021.11.009
- Peng, W., Du, H., Liu, G., Zhang, Q., Kuang, T., Wang, Z., et al. (2019). Antistress effects of San-Huang-Xie-Xin decoction on restraint-stressed mice revealed by ¹H NMR-Based metabolomics and biochemistry analysis. *Oxid. Med. Cell Longev.* 2019, 5897675. doi: 10.1155/2019/5897675
- Peng, Z. Z., and Xie, F. G. (2020). Transmission route and control measures of *Pyracantha anthracnose* in Jiuzhaigou. *Rural Pract. Tech.* 2, 76.
- Pu, S. L. (2014). *Pyracantha* propagation and cultivation management technology. *For. Pro. Spec. Chin.* 6, 56–57.
- Qin, H. B., and Wei, L. (2011). Experimental study on the antioxidant effect of pyracantha on D-galactose-induced aging mice. *J. Heze. Med. Colg.* 23, 6–8. doi: 10.3969/j.issn.1008-4118.2011.04.03
- Qin, P., Wei, Y., Hou, M., Zhao, C., and Shen, Z. (2015). [A multicenter clinical trial of caffeic acid tablet in treatment of 103 primary immune thrombocytopenia patients]. *Zhonghua Xue Ye Xue Za Zhi* 36, 103–106. doi: 10.3760/cma.j.issn.0253-2727.2015.02.004
- Ramales-Valderrama, R. A., Vázquez-Durán, A., and Méndez-Albore, A. (2016). Biosorption of B-aflatoxins using biomasses obtained from formosa firethorn [*Pyracantha koidzumii* (Hayata) Rehder]. *Toxins* 8, 218. doi: 10.3390/toxins8070218
- Ramirez-Rodríguez, A. M., González-Ortiz, M., Martínez-Abundis, E., and Acuña Ortega, N. (2017). Effect of ursolic acid on metabolic syndrome, insulin sensitivity, and inflammation. *J. Med. Food* 20, 882–886. doi: 10.1089/jmf.2017.0003
- Rojas, T. N., Vergara-Tabares, D. L., Valdez, D. J., Ponzio, M. F., and Peluc, S. I. (2019). Food supplementation by an invasive fleshy-fruited shrub sustains body condition of a native frugivorous bird during winter. *Integr. Zool.* 14, 259–269. doi: 10.1111/1749-4877.12353
- Russell, W. R., Labat, A., Scobbie, L., Duncan, G. J., and Duthie, G. G. (2009). Phenolic acid content of fruits commonly consumed and locally produced in Scotland. *Food Chem.* 115, 100–104. doi: 10.1016/j.foodchem.2008.11.086
- Saha Turna, N., and Wu, F. (2019). Risk assessment of aflatoxin-related liver cancer in Bangladesh. *Food Addit. Contam. Part A Chem. Anal. Control Expo. Risk Assess.* 36, 320–326. doi: 10.1080/19440049.2019.1567941
- Saija, A., Tomaino, A., Trombetta, D., De Pasquale, A., Uccella, N., Barbuzzi, T., et al. (2000). *In vitro* and *in vivo* evaluation of caffeic and ferulic acids as topical photoprotective agents. *Int. J. Pharm.* 199, 39–47. doi: 10.1016/S0378-5173(00)00358-6
- Sarigul Sezenoz, A., Akkoyun, I., Helvacioğlu, F., Haberal, N., Dagdeviren, A., Bacanlı, D., et al. (2021). Antiproliferative and mitochondrial protective effects of apigenin in an oxygen-induced retinopathy *in vivo* mouse model. *J. Ocul. Pharmacol. Ther.* 37, 580–590. doi: 10.1089/jop.2021.0046
- Shang, X. F., Dai, L. X., Yang, C. J., Guo, X., Liu, Y. Q., Miao, X. L., et al. (2021). A value-added application of eugenol as acaricidal agent: the mechanism of action and the safety evaluation. *J. Adv. Res.* 34, 149–158. doi: 10.1016/j.jare.2020.12.010
- Sharifi-Rad, J., Song, S., Ali, A., Subbiah, V., Taheri, Y., and Suleria, H. A. R. (2021). LC-ESI-QTOF-MS/MS characterization of phenolic compounds from *Pyracantha coccinea* M.Roem. and their antioxidant capacity. *Cell Mol. Biol.* 67, 201–211. doi: 10.14715/cmb/2021.67.1.29
- Sharifi-Rad, J., Taheri, Y., Ayatollahi, S. A., Naderi, N., Kumar, N. V. A., Koirala, N., et al. (2020). Biological activities and health-promoting effects of pyracantha genus: a key approach to the phytochemical's potential. *Cell Mol. Biol.* 66, 20–27. doi: 10.14715/cmb/2020.66.4.4
- Sharma, P., Kumar, M., and Bansal, N. (2021). Ellagic acid prevents 3-nitropropionic acid induced symptoms of Huntington's disease. *Naunyn-Schmiedeberg's Arch. Pharmacol.* 394, 1917–1928. doi: 10.1007/s00210-021-02106-1
- Shi, W., Fu, G. H., Zhng, K., and Wu, D. G. (2020). Optimization of fermentation technology of wild *Pyracantha fortuneana* health wine by response surface methodology. *China Brew.* 39, 109–114. doi: 10.11882/j.issn.0254-5071.2020.03.022
- Shim, S. Y., Lee, Y. E., Song, H. Y., and Lee, M. (2020). p-hydroxybenzoic acid β -d-glucosyl ester and cimidahurinine with antimelanogenesis and antioxidant effects from *Pyracantha angustifolia* via bioactivity-guided fractionation. *Antioxidants* 9, 258. doi: 10.3390/antiox9030258
- Su, K. Q. (2019). The research status and development prospect of three kinds of characteristic wild fruit resources in yunnan. *Farm Prod. Proc.* 4, 90–95. doi: 10.16693/j.cnki.1671-9646(X).2019.02.058
- Sun, H., Wang, X., Zhou, Z., and Wang, R. (2019). Extraction optimization of polyphenols from fruits of *Pyracantha fortuneana* (Maxim.) Li by ultrasonic assistant method and their antibacterial activity. *Pak. J. Pharm. Sci.* 32, 1635–1641.
- Sun, Q., Dong, M., Wang, Z., Wang, C., Sheng, D., Li, Z., et al. (2016). Selenium-enriched polysaccharides from *Pyracantha fortuneana* (Se-PFPs) inhibit the growth and invasive potential of ovarian cancer cells through inhibiting β -catenin signaling. *Oncotarget* 7, 28369–28383. doi: 10.18632/oncotarget.8619
- Sun, X., Li, H., Guo, X., Sun, Y., and Li, S. (2018). Capacity of six shrub species to retain atmospheric particulates with different diameters. *Environ. Sci. Pollut. Res. Int.* 25, 2643–2650. doi: 10.1007/s11356-017-0549-2
- Taheri, Y., Naderi, N., Ayatollahi, S. A., Baghalpour, N., Mahroo-Bakhtiyari, J., and Sharifi-Rad, J. (2021). High-performance thin-layer chromatography fingerprinting and anti-inflammatory and antinociceptive activities of *Pyracantha coccinea* M.Roem.: a laboratory-based study. *Cell Mol. Biol.* 67, 106–111. doi: 10.14715/cmb/2021.67.1.16
- Tang, K. H., Xun, Y., Ding, W., Li, Y. F., and Chen, G. X. (2007). A oil content of pyracantha seeds and its relations to soil nutrients in northwestern Hunan province. *Chin. J. Appl. Ecol.* 18, 1903–1907.
- Tang, Y., and Liu, J. L. (2002). Development, utilization and sustainable development of *Pyracantha fortuneana* resource in Liangshan prefecture. *Sichuan Agric. Sci. Tech.* 9, 6. doi: 10.3969/j.issn.1004-1028.2002.09.004
- Tayebati, S. K. (2018). Phospholipid and lipid derivatives as potential neuroprotective compounds. *Molecules* 23, 2257. doi: 10.3390/molecules23092257
- Teng, J. T., Cheng, Y. H., Xue, J. P., and Sheng, W. (2017). Research progress of effective components and resources development of *Pyracantha fortuneana*. *J. Huaibei Norm. Univ. Nat. Sci. Educ.* 38, 43–48.
- Thakur, B. R., Singh, R. K., and Handa, A. K. (1997). Chemistry and uses of pectin—a review. *Crit. Rev. Food Sci. Nutr.* 37, 47–73. doi: 10.1080/10408399709527767
- Tian, X. M., and Chen, K. M. (2012). Screening of *Pyracantha fortuneana* endophytic fungus and function examination of antagonism to plant pathogenic fungi. *J. N. W. For. Univ.* 27, 117–120. doi: 10.3969/j.issn.1001-7461.2012.05.22
- Tobin, P. J., Beale, P., Noney, L., Liddell, S., Rivory, L. P., and Clarke, S. (2006). A pilot study on the safety of combining chrysin, a non-absorbable inducer of UGT1A1, and irinotecan (CPT-11) to treat metastatic colorectal cancer. *Cancer Chemother. Pharmacol.* 57, 309–316. doi: 10.1007/s00280-005-0053-0
- van Dijk, A. E., Olthof, M. R., Meeuse, J. C., Seebus, E., Heine, R. J., and van Dam, R. M. (2009). Acute effects of decaffeinated coffee and the major coffee components chlorogenic acid and trigonelline on glucose tolerance. *Diabetes Care* 32, 1023–1025. doi: 10.2337/dc09-0207
- Wang, C. F., Gao, X., and Wang, X. M. (2016). Chemical composition and antioxidant activity of the oil of *Pyracantha atalantioides* fruits. *Sci. Technol. Food Ind.* 37, 81–88. doi: 10.13386/j.issn1002-0306.2016.09.007
- Wang, H., Ye, Y. H., Wang, H. H., Liu, J., Liu, Y. J., and Jiang, B. W. (2019). HPLC-QTOF-MS/MS profiling, antioxidant, and α -glucosidase inhibitory activities of *Pyracantha fortuneana* fruit extracts. *J. Food Biochem.* 43, e12821. doi: 10.1111/jfbc.12821
- Wang, J., Seyler, B. C., Ticktin, T., Zeng, Y., and Ayu, K. (2020). An ethnobotanical survey of wild edible plants used by the Yi people of Liangshan prefecture, Sichuan province, China. *J. Ethnobiol. Ethnomed.* 16, 10. doi: 10.1186/s13002-019-0349-5
- Wang, J. M., Liao, D. S., Li, Q. G., and Wang, Z. L. (1992). Study on nutritional components and pectin of *Pyracantha fortuneana*. *Food Sci.* 4, 40–42.
- Wang, R. G., Xue, C. B., Wei, M. X., Bi, F. X., and Bi, S. F. (2013). GC-MS analysis and antioxidant activity of essential oil from *Pyracantha fortuneana* fruits. *Sci. Technol. Food Ind.* 34, 95–97. doi: 10.13386/j.issn1002-0306.2013.07.018
- Wang, S. G., and Deng, R. F. (1988). Development, utilization and physiological ecology of wild plant *Pyracantha fortuneana*. *Chin Wild Plant Res.* 3, 13–15.
- Wang, X., Yang, H., Tian, R., Mo, Y., Dong, L., Shen, C., et al. (2021). Effect of the joint fermentation of pyracantha powder and glutinous rice on the

- physicochemical characterization and functional evaluation of rice wine. *Food Sci. Nutr.* 9, 6099–6108. doi: 10.1002/fsn3.2560
- Wang, X. J., Chen, L. H., and Huang, Y. L. (2015a). Antioxidant activity of flavonoids from *Pyracantha fortuneana* to oils and fats. *Nat. Prod. Res. Dev.* 27, 909–914. doi: 10.16333/j.1001-6880.2015.05.031
- Wang, X. J., Chen, L. H., and Xiang, M. F. (2016). Analysis for lipid antioxidant activity of polysaccharides from *Pyracantha fortuneana*. *Food Ferment. Ind.* 42, 175–179. doi: 10.13995/j.cnki.11-1802/ts.20160530
- Wang, X. J., Zhang, L., Chen, L. H., and Liu, M. (2015b). Cooperative antioxidation activity of *Pyracantha fortuneana* flavonoids extracts and VC. *China Oils Fats* 40, 36–40. doi: 10.3969/j.issn.1003-7969.2015.09.011
- Wei, M., Chai, W. M., Yang, Q., Wang, R., and Peng, Y. (2017). Novel insights into the inhibitory effect and mechanism of proanthocyanidins from *Pyracantha fortuneana* fruit on α -Glucosidase. *J. Food Sci.* 82, 2260–2268. doi: 10.1111/1750-3841.13816
- Wei, Z. H., Hu, L., and Huang, J. X. (2006). Effects of pyracantha syrup on the indexes related to lesion induced by arsenic poisoning in mice. *Chin. J. Tissue Eng. Res.* 10, 99–101.
- Wen, K., Fang, X., Yang, J., Yao, Y., Nandakumar, K. S., Salem, M. L., et al. (2021). Recent research on flavonoids and their biomedical applications. *Curr. Med. Chem.* 28, 1042–1066. doi: 10.2174/0929867327666200713184138
- Weng, W. J., and Gao, X. (2015). Study on antioxidant activity *in vitro* about different solvent extracts of fruits of *Pyracantha fortuneana*. *Sci. Technol. Food Ind.* 36, 77–96. doi: 10.13386/j.issn1002-0306.2015.01.008
- Wong, S. K., Chin, K. Y., and Ima-Nirwana, S. (2019). The osteoprotective effects of kaempferol: the evidence from *in vivo* and *in vitro* studies. *Drug Des. Dev. Ther.* 13, 3497–3514. doi: 10.2147/DDDT.S227738
- Xiong, H. R., Xia, L., Wen, Z. Y., Xiong, Y. F., Wang, J., and Liu, J. (2014). Studies on microwave extraction and quality of pectin in *Pyracantha fortuneana* fruit. *Chin. Agric. Sci. Bull.* 30, 271–275. Available online at: [https://kns.cnki.net/kcms/detail/detail.aspx?FileName\\$=SZNTB201403050&DbName\\$=SCJFQ2014](https://kns.cnki.net/kcms/detail/detail.aspx?FileName$=SZNTB201403050&DbName$=SCJFQ2014)
- Xu, F., and Zha, C. C. (2013). *In vivo* immune activity of *Pyracantha fruit* red pigment extract. *Guide Chin. Med.* 11, 97–98. doi: 10.15912/j.cnki.gocm.2013.18.071
- Xu, G. F. (2017). The cultivation and care of clown *Pyracantha fortuneana* 'harlequin'. *Mod. Agric. Sci. Tech.* 159–160. doi: 10.3969/j.issn.1007-5739.2017.14.102
- Xu, H., Zhao, C., Li, Y., Liu, R., Ao, M., Li, F., et al. (2019). The ameliorative effect of the *Pyracantha fortuneana* (Maxim.) H. L. Li extract on intestinal barrier dysfunction through modulating glycolipid digestion and gut microbiota in high fat diet-fed rats. *Food Funct.* 10, 6517–6532. doi: 10.1039/C9FO01599J
- Xu, H., Zhao, C. F., Tian, G. G., Qian, L. R., and Yu, L. J. (2016). Characterization of active constituents in *Pyracantha fortuneana* fruit extract and their effects on hyperlipidaemia, obesity, and oxidative stress in rodents. *J. Funct. Foods* 22, 278–290. doi: 10.1016/j.jff.2016.01.028
- Xu, J. K., Yao, X. S., Zheng, J. J., Dai, Y., and Li, Y. B. (2007). Protection of *Pyracantha fortuneana* fruit extract on liver injury in mice loaded with restraint stress. *Chin. Trad. Herb. Drugs* 12, 1849–1853. doi: 10.3321/j.issn:0253-2670.2007.12.031
- Xu, Y. F., Liu, S., Li, C. C., Fang, T. R., Qiu, F., Tao, X. Z., et al. (2015). Extraction and antioxidant activity of non-extractable polyphenols from *Pyracantha fortuneana*. *Nat. Prod. Res. Dev.* 27, 2109–2133. doi: 10.16333/j.1001-6880.2015.12.021
- Xu, Z. G., Bai, R. Y., Yan, X. M., Li, Y., Zhou, Y., Zhang, J., et al. (2021). Effect of total flavonoids from *Apocynum venetum* L. Leaves on blood lipid metabolism in hyperlipidemic rats. *Tradit. Chin. Drug Res. Clin. Pharmacol.* 32, 208–213. doi: 10.19378/j.issn.1003-9783.2021.02.008
- Xuan, S. Y., Liang, J. N., Liang, H. S., Wang, X. H., Liang, J. G., and Chen, L. (2021). Utilizing network pharmacology to explore the mechanism of flavonoids from *sophora flavescens* in diabetic retinopathy. *Guangdong Chem. Ind.* 48, 86–88. doi: 10.3969/j.issn.1007-1865.2021.08.032
- Yan, Y. Y., Shen, D. H., Wang, H. J., Wu, P., Zhao, C. F., and Yu, L. J. (2015). *Pyracantha fortuneana* procyanidins preparation and their correlation research with antioxidant activity. *Food Res. Dev.* 36, 35–148. doi: 10.3969/j.1005-6521.2015.04.010
- Yang, B., Yan, Y. Y., Zhong, F. X., and Peng, Y. R. (2011). Optimization of extraction process of proanthocyanidins from pyracantha. *Food. Nutr. Chin.* 17, 60–66. doi: 10.3969/j.issn.1006-9577.2011.05.015
- Yang, F., Duan, Y. F., and Zhou, F. (2004). Isolation & purification and antioxidation of polysaccharides in *Pyracantha fortuneana*. *Acta Bot. Boreali Occident. Sin.* 26, 2126–2130. doi: 10.3321/j.issn:1000-4025.2004.11.028
- Yao, W., Zhang, X., Xu, F., Cao, C., Liu, T., and Xue, Y. (2021). The therapeutic effects of naringenin on bronchial pneumonia in children. *Pharmacol. Res. Perspect.* 9, e00825. doi: 10.1002/prp2.825
- Yao, Y. L., Shu, C., Feng, G., Wang, Q., Yan, Y. Y., Yi, Y., et al. (2020). Polysaccharides from *Pyracantha fortuneana* and its biological activity. *Int. J. Biol. Macromol.* 150, 1162–1174. doi: 10.1016/j.ijbiomac.2019.10.125
- Yi, H., Peng, H., Wu, X., Xu, X., Kuang, T., Zhang, J., et al. (2021). The therapeutic effects and mechanisms of quercetin on metabolic diseases: pharmacological data and clinical evidence. *Oxid. Med. Cell. Longev.* 2021, 6678662. doi: 10.1155/2021/6678662
- Yoon, H., Shaw, J. L., Haigis, M. C., and Greka, A. (2021). Lipid metabolism in sickness and in health: emerging regulators of lipotoxicity. *Mol. Cell* 81, 3708–3730. doi: 10.1016/j.molcel.2021.08.027
- Younis, N. S., Elsewedy, H. S., Shehata, T. M., and Mohamed, M. E. (2021). Geraniol averts methotrexate-induced acute kidney injury via Keap1/Nrf2/HO-1 and MAPK/NF- κ B pathways. *Curr. Issues Mol. Biol.* 43, 1741–1755. doi: 10.3390/cimb43030123
- Yuan, C., Li, Z., Peng, F., Xiao, F., Ren, D., Xue, H., et al. (2015a). Combination of selenium-enriched green tea polysaccharides and Huo-ji polysaccharides synergistically enhances antioxidant and immune activity in mice. *J. Sci. Food Agric.* 95, 3211–3217. doi: 10.1002/jsfa.7287
- Yuan, C., Li, Z., Yi, M., Wang, X., Peng, F., Xiao, F., et al. (2015b). Effects of polysaccharides from selenium-enriched *Pyracantha fortuneana* on mice liver injury. *Med. Chem.* 11, 780–788. doi: 10.2174/1573406411666150602153357
- Yuan, C., Wang, C., Bu, Y., Xiang, T., Huang, X., Wang, Z., et al. (2010). Antioxidative and immunoprotective effects of *Pyracantha fortuneana* (Maxim.) Li polysaccharides in mice. *Immunol. Lett.* 133, 14–18. doi: 10.1016/j.imlet.2010.04.004
- Yuan, C., Wang, C., Wang, J., Kumar, V., Anwar, F., Xiao, F., et al. (2016). Inhibition on the growth of human MDA-MB-231 breast cancer cells *in vitro* and tumor growth in a mouse xenograft model by Se-containing polysaccharides from *Pyracantha fortuneana*. *Nutr. Res.* 36, 1243–1254. doi: 10.1016/j.nutres.2016.09.012
- Yuan, C. F., Li, Z. H., Peng, F., and Xiao, F. X. (2016). Hepatoprotective effect of *Pyracantha fortuneana* polysaccharides on liver injury induced by CCl₄ in rats. *Chin. J. Public Health* 32, 1485–1487. doi: 10.11847/zgggws2016-32-11-09
- Yuan, Z. C., Hu, Z. Z., Gao, B., Chen, P., and Wang, F. A. (2006). Development of *Pyracantha fortuneana* fruit and germinated brown rice compound fruit vinegar. *Food Ferment. Ind.* 11, 160–161. doi: 10.13995/j.cnki.11-1082/fs.2006.11.041
- Zavala-Franco, A., Hernández-Patlán, D., Solís-Cruz, B., López-Arellano, R., Tellez-Isaias, G., Vázquez-Durán, A., et al. (2018). Assessing the aflatoxin B1 adsorption capacity between biosorbents using an *in vitro* multicompartmental model simulating the dynamic conditions in the gastrointestinal tract of poultry. *Toxins* 10, 484. doi: 10.3390/toxins10110484
- Zeng, J., Yang, R., Li, Y. J., Chen, T., Yan, J. Y., Li, J., et al. (2016). Research progress on chemical constituents and pharmacological effects of *Pyracantha fortuneana*. *Hunan J. Trad. Chin. Med.* 32, 226–228. doi: 10.16808/j.cnki.issn1003-7705.2016.10.098
- Zhang, B. P., and Li, L. (2020). *Pyracantha* planting skills and application in garden landscape. *Rural Prac. Tech.* 4, 48–49.
- Zhang, H., Mao, Y. T., Ma, M. X., Ma, K., Wang, M. L., and Tao, G. C. (2017). Development of compound beverage of *Pyracantha fortuneana* and *Actinidia chinensis*. *China Brew.* 36, 177–181. doi: 10.11882/j.issn.0254-5071.2017.08.039
- Zhang, L., Liu, C., and Yuan, M. (2020). Eriodictyol produces antidepressant-like effects and ameliorates cognitive impairments induced by chronic stress. *Neuroreport* 31, 1111–1120. doi: 10.1097/WNR.0000000000001525
- Zhang, Q., Duan, H. X., Li, R. L., Sun, J. Y., Liu, J., Peng, W., et al. (2021). Inducing apoptosis and suppressing inflammatory reactions in synovial fibroblasts are two important ways for Guizhi-Shaoyao-Zhimu decoction against rheumatoid arthritis. *J. Inflamm. Res.* 14, 217–236. doi: 10.2147/JIR.S287242
- Zhang, Y., Li, M., Liu, Z., and Fu, Q. (2021). Arbutin ameliorates glucocorticoid-induced osteoporosis through activating autophagy in osteoblasts. *Exp. Biol. Med.* 246, 1650–1659. doi: 10.1177/15353702211002136
- Zhang, Y. Z., Huang, M., and Liu, S. (2014). Extraction and antioxidant effect of proanthocyanidins from pyracantha. *Asia Pac. Trad. Med.* 10, 26–28.
- Zhang, Z., Zhou, Y., Wang, S., and Huang, X. (2018). Spatial distribution of stony desertification and key influencing factors on different sampling scales in small karst watersheds. *Int. J. Environ. Res. Public Health* 15, 743. doi: 10.3390/ijerph15040743
- Zhao, C. F., Lei, D. J., Song, G. H., Zhang, H., Xu, H., and Yu, L. J. (2015). Characterisation of water-soluble proanthocyanidins of *Pyracantha fortuneana*

fruit and their improvement in cell bioavailable antioxidant activity of quercetin. *Food Chem.* 169, 484–491. doi: 10.1016/j.foodchem.2014.07.091

Zhao, J., Sun, S. Z., Guan, S. T., Zhang, H. M., and Ding, A. L. (2012). Effects of *Pyracantha fortuneana* polysaccharide on scavenging oxygen free radical and anti-lipid peroxidation. *J. Hubei Univ. Med.* 31, 464–467.

Zhou, W. B., Wang, X. J., and Gan, X. H. (2008). Study on the fermentation conditions of *Pyracantha fortuneana* vinegar in shake flasks. *J. Southwest Univ. Nat. Sci. Educ.* 30, 152–155. doi: 10.13718/j.cnki.xdzk.2008.12.014

Zhou, Y., Shan, H. T., and Wen, Y. (2017). Nutritional components analysis of *Pyracantha fortuneana* leaves in different seasons. *Feed Rev.* 10, 11–14.

Zhou, Y. J. J., Zhou, W., Long, B., Chen, Q. S., Huang, K. X., and Zhu, Y. W. (2018). Research progresses on functional components and extraction technologies of *Pyracantha fruit*. *Farm Prod. Proc.* 22, 65–68. doi: 10.16693/j.cnki.1671-9646(X).2018.11.048

Zhu, Y. H., Shi, Y. K., Fu, Q. C., Zhu, Y. W., Li, N. N., and Bi, S. F. (2013). GC-MS analysis of the chemical component of volatile oil from leaves of *Pyracantha fortuneana*. *Chem. Res. Appl.* 25, 1279–1282. doi: 10.3969/j.issn.1004-1656.2013.09.009