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A comprehensive review on secondary metabolites, nutritive value, and pharmacological effects of *Prangos ferulacea* (L.) Lindl.

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Review Paper

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Abstract:

The Apiaceae family includes the genus *Prangos*, which comprises approximately 30 species in various regions including Iran worldwide. In the Iranian rangelands, 15 species of this genus thrive. Species of *Prangos ferulacea* have been used as emollients, carminatives, tonics, anti-flatulents, and anthelmintics in traditional Iranian medicine. Several studies have investigated the chemical composition of the essential oils derived from the aerial parts, fruits, seeds, flowers, stems, and leaves of *P. ferulacea* collected from different locations of Iran. This plant also has high nutritional value for livestock. The biological activities of the secondary metabolites in the oils of *P. ferulacea* were determined. Terpenoid compounds that have long been recognized as the primary constituents of the essential oil extracted from the leaves, stems, flowers, and fruits of *P. ferulacea*, demonstrated substantial antioxidant, antibacterial, anticancer, antiviral, antispasmodic, and antidiabetic activities. The presence of coumarins, alkaloids, flavonoids, and terpenoids in this plant may facilitate the discovery of herbal medications, positioning them as potential active agents against diseases such as diabetes, cancer, HIV, and other disorders. Therefore, we believe that this review will rekindle interest in the often-overlooked *P. ferulacea* and its remarkable biosynthetic capabilities.

Keywords: *Prangos ferulacea*; Chemical compounds; Nutritive Value; Antimicrobial; Pharmacological effects

Introduction

Medicinal herbs are being used in traditional medicine to treat many diseases. Studies on medicinal plants for the treatment of various diseases, including infectious diseases (Moradi et al., 2011), cancer (Shirzad et al., 2011), diabetes (**Asgari2011a**), atherosclerosis (Hosseinpour et al., 2017), gastrointestinal disorders (Ouachinou et al., 2019), burns (Asadi et al., 2013), and neurological disorders (Akhlaghi et al., 2011) have shown satisfactory results. Although these plants are not free of side effects (Nasri and Shirzad, 2013), they usually have fewer side effects than synthetic drugs (Kaggwa et al., 2022), and in many cases, may lower the toxicity of synthetic drugs (Dégbé et al., 2018) due to the antioxidant properties (Krishnaiah et al., 2011).
Prangos ferulacea L. Lindl which is called 'Jashir' in Persian and known in Italy as common basilisk, is a valuable medicinal plant that grows in mountainous areas of Central Asia and Iran (including Zagros, northwestern highlands and parts of Alborz) (Ghahreman, 1997).
Several studies have been conducted to investigate the chemical composition of the essential oils and nutritional value of *P. ferulacea* aerial parts, fruits, seeds, flowers, stems, and leaves from various locations (Mohebi et al., 2017; Hayta and Akbaba, 2017). Chemical compounds have been shown to have a significant activity against bacteria, diabetes, cancer, HIV and other disorders (Marchese et al., 2017; Balahbib et al., 2021; Pincigher et al., 2023; Albayrak et al., 2023). However, the comprehensive phytochemical study of the species is less discussed. In other words, this systematic review can help to introduce the morphological and biosystematics properties, medicinal compositions, nutritive value, and therapeutic properties of this valuable medicinal plant to provide scientists with clinical and pharmaceutical experimental studies solutions, and also help to conserve this species and ensure its long-term use in a vari-

ety of ways. Thus, the present review aimed to summarize studies on secondary compounds, nutritive value, and the phytochemistry and pharmacological effects of secondary metabolites of *Prangos ferulacea* species and to provide a basis for the future in-depth study of the genus *Prangos*.

Methodology

An online search in three databases was performed: Web of Science, Scopus, and Google Scholar. These three databases were selected for search because of their broad inclusion of multidisciplinary topics within the medicinal plants and plant compounds domain. Each database was searched for all years included in the respective databases with the last search completed in 2024. The selected articles' criteria were developed based upon the purpose of the systematic review, to examine secondary metaboiltes and pharmacological effects of *P. ferulacea*. We tried to collect the available research using the keywords of medicinal plants and secondary compounds, nutritional value and pharmacological effects of *P. ferulacea*. From all the databases, 290 references in total were extracted. The publications' titles, abstracts, and keywords were screened based on the inclusion criteria and 105 articles were left for full-text review. About 185 articles were excluded due to lack of focus on the topic, unavailability of full text, or redundancy. Finally, after careful reading, 84 articles were selected for final review (figure 1). Outlines of the processes of analyzing, interpreting, and summarizing these selected findings are presented in Table 1.

Phytology, ecology and distribution

Prangos ferulacea belongs to the Umbelliferae family, and the genus *Prangos* includes nearly 30 species in the world. Of them, 15 species exist in the rangelands of Iran, five of which are endemic to Iran. In addition to Iran, other species of this genus are distributed in Anatolia, Caucasus, and Central Asia (Ghahreman, 1997). This species is a perennial plant that is erect and 80 – 200 cm tall and has very thick, angular, erect, reciprocal, or almost cyclic branches. The leaves are green, hairless, rarely coarse and hairy, broad, cut and divided, with linear and ribbon divisions. Flowers are yellow and complex in 6 radii, brackets, and umbrella inflorescences with 12 sharp, membranous flowers, almost toothless bowl, ovoid fruit, almost caudate, withstanding wings, much narrower than the diameter of the seed (figure 2). The flowering season is May to July. This plant grows on the high slopes of Alborz and Zagros mountains in Iran. *P. ferulacea* is one of the most important rangeland plants providing winter forage for livestock in many parts of Iran. Local ranchers consider it better than alfalfa for feeding livestock. In many villages of the western provinces,

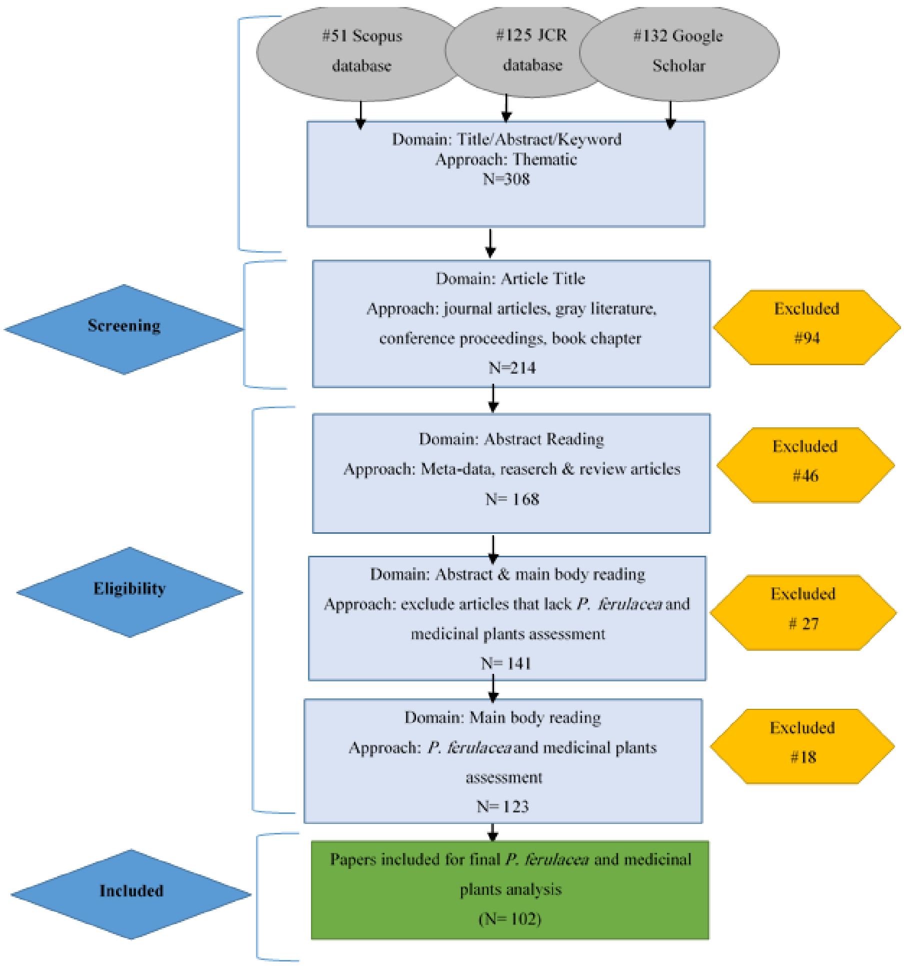

Figure 1. The flow chart of the database search of publications (Source: Authors).

Table 1. Description of previous studies on *Prangos ferulacea*.

Articles title	Number	Publication	Findings
Medicinal plants	38	From 1995 to 2023	Medicinal herbs have been used in traditional medicine to treat many diseases. Studies on medicinal plants for the treatment of various diseases show satisfactory results. The compounds identified in these plants are used as new drugs to identify low-cost and low-side-effect treatments for many diseases.
Phytology and ecology of *Prangos ferulacea*	19	From 2000 to 2023	This perennial plant is 80 – 200 cm tall and has reciprocal branches. Leaves are green, hairless, and broad. Flowers are yellow and umbrella inflorescences, ovoid fruits with withstanding wings. *P. ferulacea* grows on the high slopes of the Zagros and Alborz mountains in Iran. It is a moisture-loving plant that needs a lot of moisture, cold, and frost to complete its life cycle and is often present in areas that are snowy and have a significant cold period.
Pharmacological Effects of *P. ferulacea*	15	From 1998 to 2024	There have been numerous reports on the chemical constituents of essential oil from various parts of *P. ferulacea* from various habitats. Used in traditional medicine as windbreaks, decongestant, laxative, stomach tonic, anti-flatulence, nerve pain reliever, and an anti-inflammatory, antiviral, anti-parasitic, anti-fungal, and antibacterial agent. The essential oil of this plant was found to be effective against Staphylococcus aureus, *Staphylococcus epidermis*, *Eschrechia coli*, and *Pseudomonas aeroginosa*. The oil demonstrated significant cytotoxic activity, particularly on the MDA-MB 231 cell line, as well as moderate antioxidant properties.
Secondary Compounds and Nutritive Value of *P. ferulacea*	12	From 2002 to 2024	Was identified 39 major components, accounting for 99.99% of the total oil, including chrysanthenyl acetate, limonene, alpha-pinene, delta-3-carene, metaldehyde, and germacrene-B. The highest oil yield was obtained at the flowering stage by hydro distillation included 34 components and comprised 99.98% of the total oil. The plant's fodder quality is comparable to alfalfa. Metabolizable energy was used to determine the nutritional value of this plant, indicating that it has a high nutritional value.

such as the villages around Paveh county in Kermanshah province, local residents cultivate this plant in suitable areas. They start to harvest the forage when the leaves of the plant turn yellow, thereafter dried forage is stored. *P. ferulace* also has industrial and medicinal applications, but in most regions of Iran where it grows, it is not considered much for these purposes (Amiri, 2007).

P. ferulacea is a plant that needs moisture, cold, and frost to complete its life cycle and is often present in areas that are snowy and have a significant cold period (Mozaffarian, 1996). Its regeneration rate is better in clay soils than in other soils, and soil texture and structure have a direct role

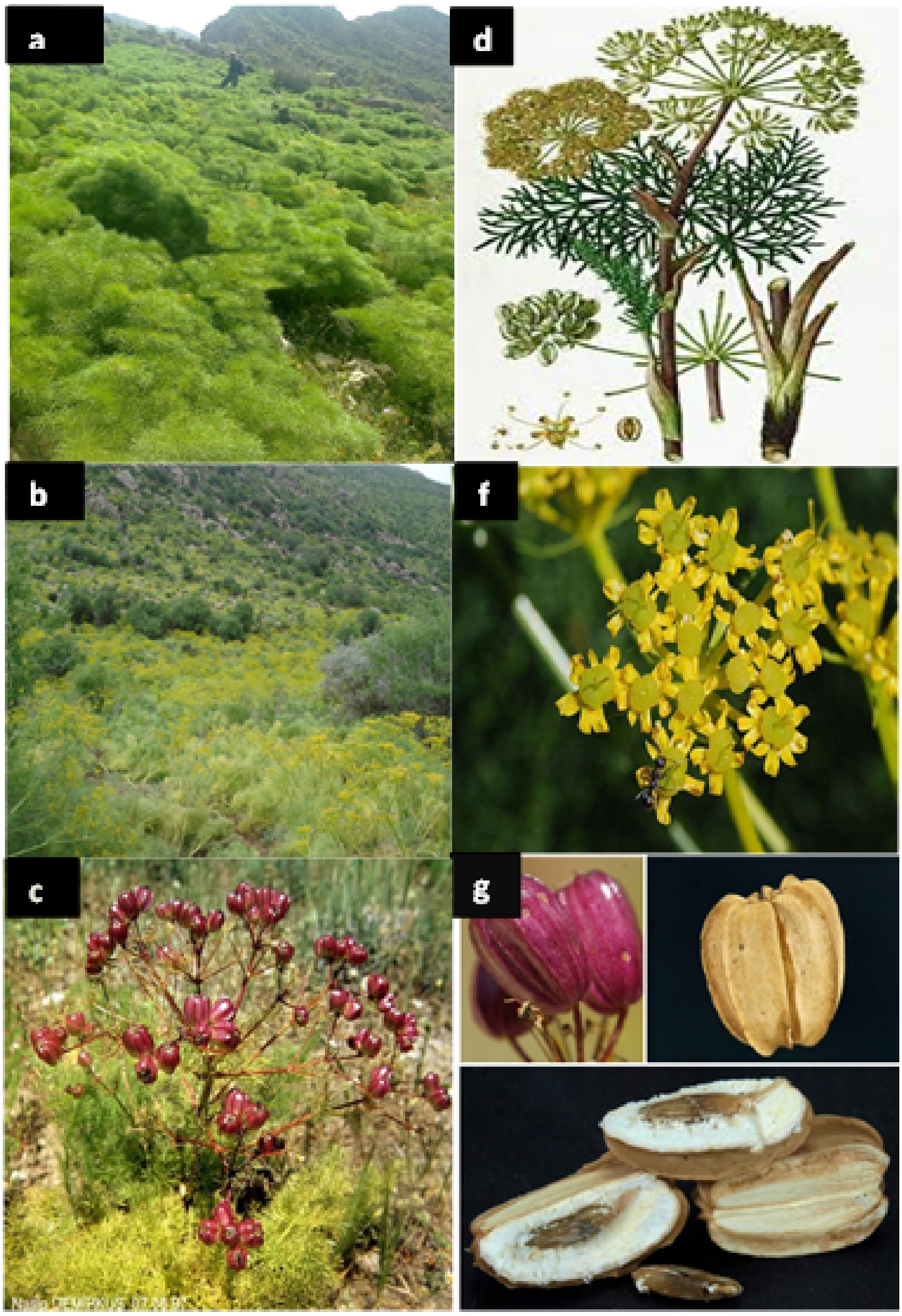

Figure 2. Introduction of growth stages and vegetative organs of the species. (a) vegetative stage, (b) flowering and (c) seeding (Mohebi et al., 2017), (d) Leaves and stems (http://bilki.bg/encyclopedia), (f) flowers, and (g) fruits, seeds.

in developing its main and secondary roots (Moghimi and Ansari, 2004). These climatic needs are met in relatively high altitudes and directions (Moghimi and Ansari, 2004). The main habitat of *P. ferulacea* in Iran is the Zagros region. This plant has been seen in the central provinces of Fars, Boyer Ahmad, Chaharmahal and Bakhtiari, Isfahan, Kermanshah, Lorestan, Hamedan, Kerman, West and East Azerbaijan, and parts of the Alborz mountains (Mohammadi et al., 2005).

Traditional medicine

P. ferulacea is used in traditional medicine as windbreaks, decongestant, laxative, stomach tonic, anti-flatulence, nerve pain reliever, and an anti-inflammatory, antiviral, antiparasitic, anti-fungal, and antibacterial agent (Başer et al., 2000). Its leaves are also used to treat gastrointestinal diseases (Hiroshi et al., 1989) and its roots are used to treat colds and enhance libido (Başer et al., 2000). Other properties of *P. ferulacea* include strengthening the nerves, re-

Table 2. Secondary metabolites from Aerial parts and root of *Prangos ferulaceae* (Mohebi et al., 2017; Hayta and Akbaba, 2017).

No.	Aerial parts			Roots		
	Compounds	**RI**	**%**	**Compounds**	**RI**	**%**
1	α-Thujene	926	0.84	Nonane	995	0.1
2	α-Pinene	949	Nd	Benzene 1-methyl-ethyl	1013	0.1
3	Sabinene	974	0.72	α-Thujene	1015	0.1
4	Myrcene	999	1.19	α-Pinene	1022	4.1
5	*p*-Cymene	1024	2.39	Camphene	1034	0.2
6	Limonene	1028	2.18	Sabinene	1051	0.3
7	δ-3-Carene	1030	3.37	β-Pinene	1055	0.3
8	1,8-Cineole	1035	0.1	β-Myrcene	1064	0.6
9	γ-terpinene	1075	0.1	α-Phellandrene	1078	9.7
10	Terpinolene	1081	0.61	α-Terpinene	1085	0.1
11	Dehydro linalool	1092	1.29	*p-Cymene*	1092	5.1
12	Linalool	1097	3.46	β-Phellandrene	1099	18.9
13	Octen-3-yl-acetate	1114	0.83	β-Ocimene	1107	0.7
14	Myrcenol	1121	1.16	γ-Terpinene	1116	0.1
15	3-Octanol acetate	1122	1.01	α-Terpinolene	1139	14.2
16	-1-Terpinoel	1133	0.33	Undecane	1147	0.1
17	p-Cymene-8-ol	1183	0.45	1.3,8-Para menthatriene	1156	0.1
18	*cis*-pinocarvyl acetate	1313	0.34	*p-Menth-2-en-1-ol*	1165	0.1
19	α-longipinene	1353	0.82	4-Terpineol	1205	0.1
20	Nevyl acetate	1364	0.68	Crypton	1209	0.2
21	Italicene	1405	0.5	Trans-carveol	1230	0.1
22	E-Caryophyllene	1420	48.21	*p-Mentha 1.5 dien-7-ol*	1272	0.1
23	α-Humulene	1450	10.28	Phellandral	1276	0.1
24	E-β-Farnesene	1458	3.21	Carvacreol	1296	0.1
25	7-epi-1,2-dehydro sesquicineol	1471	0.72	*p-Vinyl guaiacol*	1304	0.1
26	γ-Muurolene	1480	1.30	Methyl cumate	1357	0.1
27	Epi- cubenol	1493	0.39			
28	α-selinene	1497	0.78			
29	Spathulenol	1577	6.73			
30	Caryophyllen oxide	1582	0.41			
31	globulol	1586	0.80			
32	β-eudesmol	1650	0.73			
33	α-bisabolol	1684	4.25			
34	β-Bisabolene	1790	0.2			

RI : Retention indices as determined on a DB-5 column using the homologous series of n-alkanes

lieving the congestion and obstruction of ducts, crushing kidney and bladder stones, and reducing splenitis (Mavi et al., 2004). Although different parts of *P. ferulacea* have been used as a traditional herbal remedy for its beneficial effects on human diseases, detailed biosynthetic experiments and clinical trials are required to confirm the use of this plant for the treatment of diseases.

Essential oil analysis

There have been numerous reports on the chemical constituents of essential oil from various parts of *P. ferulacea* from various habitats (Amiri, 2007; Razavi et al., 2010; Mohebi et al., 2021; Zadeh et al., 2022). The essential oil of *P. ferulacea*'s chemical composition and antibacterial properties were analyzed using Gas Chromatography (GC) and Gas Chromatography/Mass Spectrometry (GC/MS). Chrysanthenyl acetate (26.53%), limonene (19.59%), alpha-pinene (19.50%), delta-3-carene (6.56%), metaldehyde (6.09%), and germacrene-B (6.09%) were the primary constituents of the 39 detected constituents, accounting for 99.99% of the total oil. The antibacterial effects of the essential oil on both gram-positive and gram-negative bacteria were examined. The essential oil of this plant was found to be effective against *Staphylococcus aureus*, *Staphylococcus epidermis*, *Eschrechia coli*, and *Pseudomonas aeroginosa* (Massumi et al., 2007).

Başer et al. (2000) investigated the essential oils of *Prangos uechritzii* Boiss by water distillation and micro distillations and identified 109 compounds. Other methods such as FTIR, HRESIMS, NMR, and GC have identified a new Bisabolene derivative. Another research analyzed the essential oil constituents of the aerial parts and seeds of *P. ferulacea* and identified 25 compounds in the aerial parts and 12 compounds in the seeds of this plant, of which Epi-α-bisabolol (7.7%), δ-3- Carene (16%), alpha-pinene (12.6%), and beta-pinene (22.9%) were the main constituents of the aerial parts and alpha-pinene (10%), δ-3-Carene(10%), limonene (8.9%), and beta-pinene (23%) were the main components of the seeds of this plant. They also reported beta-caryophyllene (18.2%, germacrene D (17.2%), and limonene (8.7%) as the main constituents of the essential oils of the aerial part (Sefidkon and Navaii, 2001). Also, The essential oils of fertile and infertile individuals were separated from the aerial parts by steam distillation and hydrodistillation procedures at three maturity stages of pre-flowering, flowering, and seeding to obtain the best oil production of *P. ferulacea*. Regarding hydrodistillation and steam distillation, the extraction yields from the aerial portions of *P. ferulacea* were determined to be $0.24-0.29\%$ and 0.17%, respectively. For hydrodistillation, the flowering stage in individuals produced the maximum oil production (0.29% w/w) (Mohebi et al., 2017).

Amiri (2007) showed that the essential oil yield of *P. ferulacea* was 1.6%. As the results show, almost all the compounds in this species' essential oil are monoterpenes, among which alpha-phenine (36.6%) and beta-pinene (31.9%) are the most important compounds in the essential oil of this plant, which together make up 68.5% of the essential oil. Other indicators of monoterpene compounds include beta-flandren (11.7%) and alpha-terpinoline (6.9%). The only known sesqui-terpene compound of this essential oil is beta-caryophyllene (1.3%). Table 2 lists the main compounds of *P. ferulaceae* Aerial parts and root. 34 components, accounting for 99.98% of the total oil, were found with (E)-caryophyllene (48.21%), -humulene (10.28%), spathulenol (9.36%), linalool (3.46%), and -3-carene (3.37%) recognized as the major components (Mohebi et al., 2017). Also, 26 compounds were reported in the root of the plant (Hayta and Akbaba, 2017). On the other hand, studies have shown that these species are very rich in by-products such as terpenoids, alkaloids, and flavonoids, most of which have antimicrobial effects. Yet, they have received less attention so far (Gyawali and Ibrahim, 2014).

Quercetin metabolites include isorhamnetin derivatives. Numerous species of the Brassicaceae family, such as red turnip and mustard, contain these substances. Isorhamnetin was found in the *Peucedaneae* and *Apieae* tribes of the Apiaceae family (Harborne and Williams, 1972). The presence of isorhamnetin 3-O-D-glucoside and isorhamnetin 3-O-D-glucorhamnoside in the aerial parts of *P. ferulaceae* is reported in this study. Thus, it is worth noting that isorhamnetin 3-O-D-glucorhamnoside can be regarded as a distinctive flavonoid in *P. ferulaceae* (Razavi, 2012).

(Bruno et al., 2021) investigated the essential oil composition and biological activities of a *P. ferulacea* accession from Sicily. A novel chemotype that was extremely rich in the b-ocimene isomers Z and E was identified after analyzing the essential oil of the Sicilian accession of *P. ferulacea*. The chemical analysis of the essential oil of the Sicilian accession of *P. ferulacea* led to the identification of a new chemotype that was very rich in the isomers Z and E of b-ocimene. The oil demonstrated significant cytotoxic activity, particularly on the MDA-MB 231 cell line, together with mild antioxidant qualities. However, its *in vitro* AChE inhibitory actions are extremely effective, making this oil a potentially effective treatment for neurodegenerative diseases. Figure 3 depicts the structures of compounds $(1-5)$ isolated from *P. ferulacea* aerial parts.

In this article, a total of 52% of metabolites from plant aerial parts and roots included coumarins, alkaloids, flavonoids, and terpenoids, among which the most of compounds are terpenoids. Some of the biological properties of important chemicals isolated from this plant were discussed in the following sections.

Nutritional value (Fodder value)

In addition to the high yield of essential oil, this plant also is well-known as a source of high-quality forage for herbivores (Coskun et al., 2004). Due to the essence of aerial parts, they are not used in green to feed livestock. Instead, they are chopped green and dried before being used to feed livestock in the winter. As a result, in many parts of Iran, it is one of the most important plants for providing winter food for livestock (Moghimi and Ansari, 2004). The plant's forage quality is comparable to alfalfa (Coskun et al., 2004). Also, metabolizable energy was used to determine the nutritional value of this plant, indicating that it has a high nutritional value (Coskun et al., 2004; Mohebi et al., 2016).

Studies show that different livestock (cattle, sheep, and goats) only the plants around *P. ferulacea* in the habitats of the species (Farid, 1991). The presence of large amounts of coumarin in the green organs of *P. ferulacea* (Ahmed et al., 2011) and its unpleasant odor probably prevent grazing in the growing stages. Therefore, an experiment in Iran has shown that after the chemical decomposition extraction, this plant can be used as a high-energy and high-quality forage for livestock (Mohebi et al., 2016) (Table 3). The most significant minerals found in *P. ferulacea* were calcium (68350 ± 0 µg/kg), potassium (112550 ± 3309.2 µg/kg) and phosphorus (1305 ± 5.7 µg/kg), copper (1291 ± 18.4 µg/kg), iron (6371 ± 2159.9 µg/kg), magnesium (24605 ± 2166.3 µg/kg), sodium (1216 ± 45.4 µg/kg), and zinc(2690 ± 17.6 µg/kg), according to another study (Atamanalp et al., 2017).

Thus, *P. ferulacea* is rich in a variety of vital elements, including calcium, potassium, iron, magnesium, sodium, and zinc. It also includes a high concentration of proteins and carbohydrates that are suitable for feeding fulfilling the nutrition requirements of grazing animals. As a result, this species can play an important role as an alternative forage

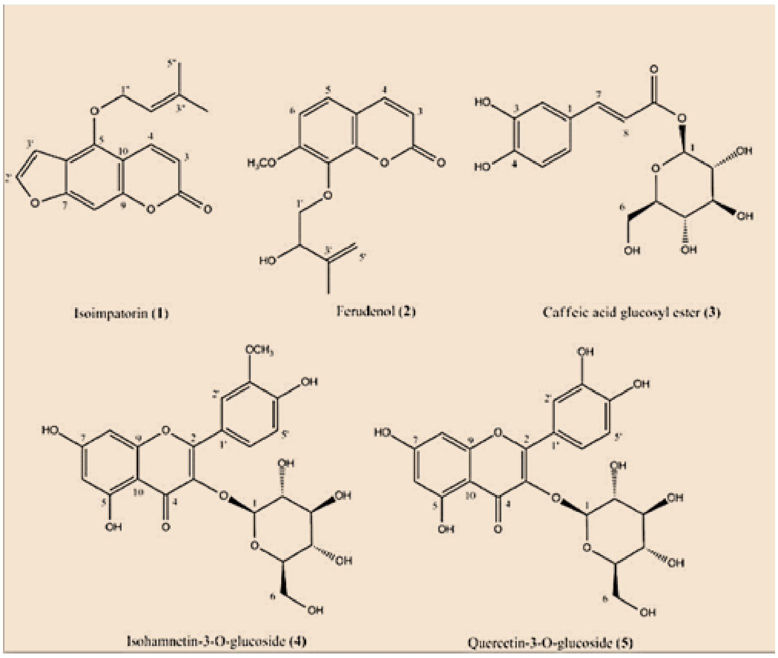

Figure 3. The structures of compounds (1 − 5) were isolated from the aerial parts of *P. ferulacea* (Delnavazi et al., 2017).

resource for livestock in winter.

Allelopathic effects and insects control

Our findings show that the essential oil quality in *P. ferulacea* leaves varies dramatically depending on the stage of growth (Amiri, 2007). E-anethole, which predominates during the flowering stage (accounting for up to 95.5 percent of the oil), was found in low concentrations during the vegetative stage (Razavi et al., 2010).
According to the literature, E-anethole has a variety of biological activities. It has been reported to have antiproliferative and mosquitocidal properties (Rahman and Basha, 2000; Berger, 2007). Based on the activity at a given dose and exposure period, E-anethole was also identified as the most active fumigant against all pest species (Erler and Tunc, 2005). As a result, the presence of E-anethole is thought to be responsible for the fungal and phytotoxic effects of *P. ferulacea* leaves during the flowering stage. The current study discovered that *P. ferulacea* essential oils have some allelopathic properties that allow them to be classified as allelochemicals (Razavi, 2012).
Previous research has shown that pinene is predominately found in the essential oils of plant umbels and fruits (Khakdan et al., 2016). Pinene, like other monoterpenes, attracts insects during the pollination and seed dispersal process. It is hypothesized that biosynthetic pathways shift to produce such allelochemicals as anethole during the reproductive stage. This modification may protect a plant from herbivorous insects (Razavi, 2012). Therefore, allelochemicals from plants can be used to control weeds, pathogens, pesticides, insects, and nematodes. The use of synthetic herbicides, fungicides, and insecticides is thought to harm the environment. They also do not provide an appropriate means of controlling pathogen resistance. In a study, the efficacy of *P. ferulacea* against the larvae of Cx. Quinquefasciatus and Anopheles Stephensi were investigated. During the bioassay experiments, the strong larvicidal properties were shown by the oils of different parts of the plant (Akrami et al., 2022).
Allelopathy research presents a challenge in developing new concepts for the next generation of natural phytotoxins used as herbicides, fungicides, insecticides, and resistant crop varieties. The phenomenon of allelopathy is also ecologically significant in natural ecosystems. It is crucial in determining

Table 3. The nutrient compositions (%) of *P. ferulacea* at the flowering stage (Mohebi et al., 2016).

Nutrient compositions (%)	Abbreviation	Aerial parts
Digestible dry matter	DDM	68.25 ± 0.11
Crude protein	CP	26.02 ± 0.25
Water-soluble carbohydrate	WSC	19.53 ± 0.10
Acid detergent fibre	ADF	36.36 ± 0.09
Crude fibre	CF	18.42 ± 0.12
Natural detergent fibre	NDF	35.46 ± 0.08
Metabolizable energy	ME	9.60 ± 0.02

plant diversity, plant dominance and sociability, succession, and natural vegetation climax (Reigosa et al., 2006). Thus, More research is needed to determine the true allelopathic potential of *P. ferulacea* oils when grown under real-world farming conditions. Some isorhamnetin-based compounds have also been shown to play ecological roles in the plant. An isorhamnetin aminoglycoside has been shown to operate as an attractant or stimulant for pollinating insects (Kim and Mullin, 2007). Similar substances may affect plants in an allelopathic way, decreasing seed germination or seedling growth in nearby plants (Rhodes, 1994).

Medicinal effects

Previous phytochemical studies have shown the presence of coumarins, alkaloids, flavonoids, and tritonoids in this plant (Razavi et al., 2010; Mohebi et al., 2017). Some important compounds such as amyliferon, frandolol, ferrolidine, prangon, and pentyl coumarin have also been identified in the roots of *P. ferulacea* (Coruh et al., 2007). Previous studies have shown antioxidant compounds in jashir (Cesur et al., 2017). The administration of *P. ferulacea* plant extract effectively prevents many diseases including histopathological changes, diabetes, oxidative stress and microbial diseases (Soltani et al., 2011; Azadpour et al., 2018; Abdollahnezhad et al., 2020). The biological activities of oils and secondary metabolites of *P. ferulacea* are listed in Table 4.

Antimicrobial effects

The results of antimicrobial effects of *P. ferulacea* essential oil showed that the essential oil of the plant has significant antimicrobial effects against gram-positive strains of *Staphylococcus epidermidis* and *Staphylococcus aureus* (diameters of growth inhibition zone of 22 and 35 mm, respectively) and gram-negative strains of *salmonella typhi*, *Shigella flexneri*, and *Escherichia coli* (diameters of growth inhibition zone of 25, 28, and 20 mm, respectively) (Dorman and Deans, 2000). There were no significant antimicrobial effects only for *Pseudomonas aeruginosa*. The essential oil of this plant has a moderate antimicrobial effect on *Staphylococcus saprophytes*.
The antimicrobial effects of *P. ferulacea* essential oil can be attributed to the high levels of monoterpene compounds, especially alpha pinene (Dorman and Deans, 2000). Therefore, the essential oil of the species can be considered compounds with strong antimicrobial effects and natural origin.

Antioxidant properties

The *P. ferulacea* has a lot of antioxidants. The antioxidant effects of this plant have been reported from alpha-tocopherol (vitamin E), and the plant extract has been shown to affect glutathione-S-transferase (GST) activity (Coruh et al., 2007). This property of the plant has been directly related to the presence of coumarins, alkaloids, flavonoids, and terpenoids (Sajjadi and Mehregan, 2003). Further, the presence of phenolic compounds in *P. ferulacea* confirms the high antioxidant properties of this plant (Coruh et al., 2007). However, in a study conducted by (Razavi et al., 2010), one of the newly identified flavonoids in the essential oil of the plant called quercetin-3-O-glucoside did not affect the antioxidant effects of the species. Also, The biological actions of isorhamnetin derivatives have been the subject of various studies. These compounds may contribute to improve heart health because of their antioxidant and anticancer characteristics. Compounds' potential to lessen diabetes sequelae such as diabetic cataracts, lipid peroxidation, and high blood sugar levels has also been studied in several research (Lee et al., 2005). On the other hand, *P. ferulaceae*'s pharmacological and biological activities have been the subject of numerous reports (Shikishima et al., 2001). Distinct flavonoids and furanocoumarins found in diverse plant portions probably are what cause these bioactivities.
Previous research has shown that essential oils with these monoterpenes as main constituents have antioxidant activity (Valente et al., 2013; Khakdan et al., 2016). Furthermore, the essential oil contains α-pinene, sabinene, and carvacrol, all of which have been shown to have significant antioxidant activities (Kapoor et al., 2012). Thus, the abundance of β-ocimene isomers in *P. ferulacea* essential oil along with a minor amount of α-pinene, sabinene, and carvacrol may contribute to the overall antioxidant effects of the oil (Bruno et al., 2021). Cesur et al. (2017) investigated the antioxidant activity of *P. ferulacea*. Fruit extracts from Turkey. They evaluated the DPPH radical scavenging activity and total phenolic and flavonoid compounds of fruit extracts. The time of collection had a significant impact on the quality of medicinal and aromatic plants. To investigate the variation in collection periods, the impact of seasonal fluctuation on the DPPH radical scavenging activity, and the amount of total phenolic and flavonoid components in the extracts, the plants were harvested at two distinct times (May and July). According to the analysis's findings, there was little antioxidant activity in the fruit extracts that were collected at two distinct times. However, the solvent, concentration, and fruit collecting period all had impact on the antioxidant capabilities of these extracts.

Anti-diabetic properties

The anti-diabetic activities of *P. ferulacea* showed that treatment of diabetic mice with hydroalcoholic extract of *P. ferulacea* root at a dose of 100 mg/kg caused a significant reduction in blood glucose levels, total cholesterol, triglyceride, LDL, and glycosylated hemoglobin (HbA1c), a significant increase in HDL levels, and normalization of white blood cell (Soltani et al., 2011). *P. ferulacea* extract significantly improved many lesions of kidney, liver, and pancreas tissues and showed most of the adverse tissue changes, including necrotic foci, tissue atrophies, and increased lymphocytic attack in some areas. In another study, the plant extract was effective in improving liver and kidney damage due to diabetes and led to a significant increase in blood indicators of liver function, including Creatinine, AST, and ALT (Mokhtari and Mohammadi, 2012). The presence of umbelliferone and coumarins extracted from the roots of the plant as well as flavonoid compounds, all of which have antioxidant properties, can be one of the reasons for the effectiveness of plant root extract in improving the biochemical and histological complications of diabetes (Farkhad et al., 2012).

Table 4. Bioactivities of important secondary metabolites from *P. ferulaceae*.

Compound	Plant material	Biological activities	References
α-Thujene	Aerial, roots	Antioxidant, antibacterial	(Shafaghat and Shafaghatlonba, 2011), (Zeraib et al., 2014)
α-Pinene	Aerial, roots	Antimicrobial, antioxidant, anti-inflammatory and anti-carcinogenic.	(Rivas et al., 2012), (Tlak and Dar, 2021)
β-Pinene	Roots	Analgesic, antimicrobial, anticoagulant, antitumor, antioxidant, anti-inflammatory	(Rivas et al., 2012), (Salehi et al., 2019)
Sabinene	Aerial, roots	Antioxidant, treatment decreases the generation of oxidative stress, angiostatic, antiangiogenic.	(Sharma et al., 2019)
Camphene	Root	Antibacterial and anticancer, used in pulmonary disease.	(Girola et al., 2015), (Hachlafi et al., 2021)
Myrcene	Aerial parts	Anticancer, antifungal	(Pincigher et al., 2023), (Albayrak et al., 2023)
***p*-Cymene**	Aerial parts	Antimicrobial, antioxidant, anti-inflammatory, antidiabetic, antiviral, antitumor, antifungal	(Marchese et al., 2017), (Balahbib et al., 2021)
α-Terpinene	Roots	Antioxidant, analgesic, anti-inflammation	(Rudbäck et al., 2012)
γ-terpinene	Aerial, roots	Antibacterial, Analgesic, anti-inflammation	(Zochedh et al., 2022), (Pina et al., 2024)
Terpinolene	Aerial, roots	Antioxidant, larvicide, insecticide	(Menezes et al., 2021)
Limonene	Aerial parts	Antibacterial, antifungal and food preservation.	(**Young2017**)
δ-3-Carene	Aerial parts	Antimicrobial effect against some food-borne pathogenic bacteria, used also as food additive.	(Falk et al., 1991), (Shu et al., 2019)
1,8-Cineole	Aerial parts	Anticancer, antioxidant, analgesic, anti-inflammation	(Cai et al., 2021)
Linalool	Aerial parts	Anti-anxiety, sedative, anticonvulsant, anti-Alzheimer, antibacterial	(Goswami et al., 2016), (Hosseini et al., 2021)
β-Myrcene	Roots	Anxiolytic, antioxidant, anti-aging, anti-inflammatory, analgesic properties	(Surendran et al., 2021)
α-Phellandrene	Roots	Antitumoral, antinociceptive, larvicidal, insecticidal, anti-inflammatory	(Radice et al., 2022), (Thangaleela et al., 2022)
E-Caryophyllene	Aerial parts	Anticancer, analgesic, antibacterial	(Montanari et al., 2011), (Fidyt et al., 2016)
α-Humulene	Aerial parts	Antitumor activity, anti-inflammatory, antimicrobial	(de et al., 2021)
E-β-Farnesene	Aerial parts	Antimicrobial, antitumor, insecticidal activity	(Qin et al., 2015), (Satyal et al., 2015)
Spathulenol	Aerial parts	Antioxidant, antimycobacterial, anticancer, anti-inflammatory	(do et al., 2018)
Caryophyllene oxide	Aerial parts	Antifungal, decreases platelet aggregation, cytotoxic activity	(Jun et al., 2011), (Jassal et al., 2021)
α-bisabolol	Aerial parts	Anti-anxiety, anticancer, anti-inflammatory, antiinfection	(Ramazani et al., 2022)
Carvacreol	Roots	Antiviral, antimicrobial	(Rathod et al., 2021), (Mączka et al., 2023)

Antibacterial and antiviral properties

The effectiveness of four extracts of *P. ferulacea* (ethanolic, methanolic, aqueous, and n-hexane) against several gram-positive bacteria, such as *Bacillus subtilis*, *Bacillus cereus*, *Staphylococcus aureus*, and *Micrococcus luteus*, and gram-negative bacteria, such as *Escherichia coli*, *Proteus mirabilis*, *Klebsiella pneumoniae*, and *Salmonella enteritidis* have been studied. Most of the antibacterial properties have been attributed to the ethanolic and methanolic extracts of the plant, each of which has significantly strong antibacterial properties (Durmaz et al., 2006). Other studies have shown the antibacterial properties of *P. ferulacea* fruit essential oil against gram-positive and gram-negative bacteria such as *Escherichia coli*, *Staphylococcus aureus*, *Pseudomonas aeroginosa*, *Staphylococcus epidermis*, and Bacillus cereus. In these studies, the presence of compounds such as limonene, α-humulene, and α-pinene has been regarded as reasons for the effectiveness of this plant and the emergence of antibacterial properties (Razavi and Hajiboland, 2009).

Recently, there have been reports of cytokine release inhibitors and anti-HIV effects of species of *P. ferulacea* that several important coumarins extracted from the roots of *P. ferulacea* had cytotoxic properties and antiviral effects against HIV (Gholamzadeh et al., 2012).

Antitumor activities

Several studies have been conducted on the cytotoxic and antitumor properties of E-Caryophyllene, α-Humulene, E-β-Farnesene, and α-Phellandrene, the main components of the essential oil of the aerial parts and root (Qin et al., 2015; Fidyt et al., 2016; de et al., 2021; Radice et al., 2022). For example, some results showed that the two compounds E)- β-Caryophyllene, α-Humulene increased the activity of an enzyme, Glutathione S-transferase, in the liver and the small intestine mucosa of mice (Zheng et al., 1992). These findings suggested that substances capable of inducing an increase in the activity of this enzyme, which is characterized as a detoxifier, in addition to being a significant agent in the protection against oxidative stress could be potential carcinogenesis inhibitors (Tuerlinckx et al., 2018). α-Pinene was found to be slightly active in the tumor cells, with the greatest inhibition on MDA-MB 231 cells (Woguem et al., 2014). On melanoma cells, this compound also has antimetastatic and apoptotic properties (Matsuo et al., 2011). As a result, the cytotoxic effects of *P. ferulacea* essential oil can be attributed to its main constituents, though the contribution of some minor constituents cannot be discounted (Bruno et al., 2021).

Analgesic effects

In traditional medicine, *P. ferulacea* has been used as an analgesic to relieve many aches and pains, including toothache, bone fracture pain, contusion, flank pain, headache, muscle aches, and many similar aches and pains. Recently, in an in vitro study, the analgesic effects of aqueous and alcoholic extracts of *P. ferulacea* on pain induced (both central and peripheral) by formalin in female rats were investigated. In this study, the administration of aqueous extract of *P. ferulacea* at a dose of 100 mg/kg reduced pain in phase 2 of the formalin test, and also the administration of 300, 900, and 1350 mg/kg doses resulted in pain reduction in phases 1 and 2 of the test. Moreover, the 200 mg/kg methanolic extract of this plant reduced pain in phase 2 of the formalin test, and 400 and 800 mg/kg doses reduced pain in phases 1 and 2 of this test. The presence of compounds such as s saponin, anthraquinone, tannins, and flavonoids in plant extracts have been introduced as possible reasons for the analgesic effects of the species (Emamghoreishi et al., 2011).

In addition, the abortifacient effect of *P. ferulacea* on rats has shown that only some doses of plant leaf extract increase the number of abortions in pregnant mice, but this increase is not significant and is not correlated. No difference was observed between the dose and type of extract and the number of abortions. Certainly, further studies are needed to examine other doses to determine the presence or absence of this property in *P. ferulacea* (Sadraei et al., 2013).

Antispasmodic effects

One study assessed the effects of *P. ferulacea* (roots and aerial parts) on the relaxing and contraction of the uterine smooth muscle in female rats and reported the antispasmodic effects of the plant extract on contraction especially against oxytocin-induced contraction. This property might be due to the presence of one of the most important coumarins in this plant, which causes the emergence of properties mentioned in *P. ferulacea* by blocking calcium ostiole channels. It also plays an important role in the delivery process (Sadraei et al., 2013).

Conclusion

The current study summarizes the most significant phytochemicals and organic properties of *P. ferulacea*, a species that has been utilized for centuries in various countries for its antispasmodic, narcotic, analgesic, anti-inflammatory, sterile, antiviral, and antimicrobial properties. The most extensively studied feature of this species is its antimicrobial activity. Both extracts and essential oils have demonstrated promising results, corroborating traditional ethnic uses. Although some flavonoids have been identified, coumarins are the most abundant constituents. These secondary metabolites, primarily prenyl-coumarins and furanocoumarins, exhibit cytotoxic activities, warranting further investigation. Despite the extensive number of studies conducted, additional research is necessary to enhance our understanding of this species. Given that the potential health risks associated with *P. ferulacea*-derived products have not been thoroughly investigated, more comprehensive research is essential before these products can be utilized for future pharmacological and commercial applications.

Authors Contributions
All authors have contributed equally to prepare the paper.

Availability of Data and Materials
The data that support the findings of this study are available from the corresponding author upon reasonable request.

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

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