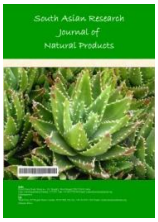

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Antioxidant and Antimicrobial Activity of *Ferula* Species' Essential Oils and Plant Extracts and their Application as the Natural Food Preservatives

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Authors' contributions

This work was carried out in collaboration among all authors. Author MD designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors MHM, MAM and VJK managed the analyses of the study. Authors KA and HA managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Ferula is a genus of perennial herbs in the Apiaceae family. Members of this genus are found mainly in the Mediterranean region and Central Asia, and they have a long history of utilization in traditional medicine for a variety of diseases. The species of this plant have been used for the ole-gum resin, plant extracts, and essential oils. *Ferula* species typically have a heavy fragrance due to the presence of essential oils or oleoresins in them. This review aimed to investigate the antibacterial, anti-fungal, and antioxidant activity of essential oils and plant extracts of *ferula* species and their potential to be used as natural food preservatives. Potential antioxidant and antimicrobial activity due to the specific chemical compounds have approved that the essential oils and extracts of different species of this plant can be utilized as natural food preservatives. Although an array of studies have approved these activities, there are still some vague aspects of their application for the extension of different food products' shelf life and replacement for synthetic (artificial) preservatives.

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Keywords: Antioxidant; antimicrobial; essential oil; extract; ferula; preservative.

1. INTRODUCTION

Given current market expectations, food product protection with nutritional content and sensory qualities is a primary industrial goal. Besides, the food industry's ever-increasing competitiveness had made cost-cutting inevitable [1]. Follow by these trends, due to the globalized nature of the food industry and the remote delivery of goods in recent years, research and development have focused on stable, advanced innovations that extend the shelf-life of a food product while maintaining its fresh quality [2]. Studies have been looking for antimicrobials and antioxidants to replace synthetic ones, with natural substances implying their importance as historically accepted therapeutic agents [3]. Antioxidants, which may extend food shelf life, must be used in foods to inhibit the activity of free radicals. Currently, synthetic antioxidants are becoming less popular due to their adverse health effects, while natural antioxidants are becoming more widespread [4]. While the efficacy of natural antioxidants and antimicrobial compounds applied to food products is a cause of concern, research on the use of herbal extracts and essential oils in the stabilization of food products such as edible oils have been conducted, with promising results in the majority of experiments [5-11]. There are over 1340 plants with established antimicrobial activities to date and more than 30,000 plant-isolated antimicrobial compounds. *Ferula* species have been classified as a rich source of antimicrobial compounds [12-20]. These species produce alkaloids, flavonoids, isoflavonoids, tannins, coumarins, glucosides, terpenes, and phenolic substances that are secondary metabolites. These chemicals with antimicrobial properties have practical food safety applications, avoiding bacteria and fungi infections [21,22].

There are more than 150 species of *ferula*, which are primarily distributed in the Mediterranean region and Central Asia. This species belongs to the Apiaceae family, which is made up of 275 genera and 2850 species. Many functional compounds were isolated from *ferula*, including sesquiterpenes, sesquiterpene coumarins, and sulfur-containing compounds. Research findings of more than 70 species have shown that the principal components of this species are germacranes, humulanes, carotanes, himachalanes, and guaiaanes [2,12,23].

The *ferula* plants, on the whole, have an upright perennial plant up to 3 m long, with deeply dissected leaves, a fleshy taproot, and inconspicuous yellow flowers borne in compound umbels. The plant has a perennial fusiform root, either simple like parsnip, with a coarse, hairy summit. The bark is wrinkled and black with large quantities of dense alliaceous juice. The leaves, where such lobes are oblong and obtuse, are shiny. In number, they are few and appear in autumn. The stem is solid, smooth, herbaceous, and clothed with membranous sheaths. The fruits, with vittae, are thin, flat, foliaceous, and reddish-brown [24-26].

Derived plant extracts and essential oils from various parts of the plant are the two sources of compounds with biological activities in *ferula*. Asafoetida (*Ferula* asafoetida) is an oleogum resin extracted from the *ferula* plant affiliated with the Umbelliferae family. Asafoetida derives from the Persian *aza*, for mastic or resin, and *foetidus*, for stinking, from the Latin. Asafoetida or similar oleo gum resins are obtained from *F. assa-foetida*, *F. foetida*, and *F. narthex*; gum galbanum from *F. galbaniflua* (*F. gummosa*) and *F .rubicaulis* [24,25]. Ancient documents note that this substance "stink finger" was brought west in 4 B.C. by Alexander. It was known as "the food of the Gods" to the early Persians and as Persian sylphium to the Romans. The Europeans likened their fragrance to truffles and named asafetida, the dung of the devil [24]. It was used as a flavor in ancient Rome and has been used for centuries in Indian cuisine. Asafoetida was used as a condiment and as a drug in ancient India and Iran. Even currently, it is a common ingredient in Indian cuisine, most likely because its fragrance recalls the scent of garlic and onion, two sprouting vegetables, as well as meat [24,28]. Asafoetida has a strong odor that is tenacious and sulfurous. Traditionally, asafoetida is used to treat multiple illnesses such as whooping cough, asthma, ulcer, epilepsy, stomach pain, flatulence, bronchitis, bowel parasites, antispasmodic illness, impaired digestion, and influenza [29-32]. Several actions have also been shown throughout recent pharmacological and biological trials, such as antioxidant, antimicrobial, antiviral, anti-fungal, chemopreventive, anti-diabetic, anti-carcinogenesis, antispasmodic, and hypotensive, relaxant, neuroprotective and molluscicidal effects of asafoetida [33-43].

Fig. 1. Two *ferula* species [27]

Herbal extractions and essential oils have been used for pharmacological purposes such as antibacterial, anti-fungal, antiviral, antiparasitic, insecticidal, and antispasmodic throughout history. Currently, they are bing used in the pharmaceutical, sanitary, cosmetic, agricultural, and food industries [5]. Essential oils are a type of liquid that is subtle, highly concentrated, aromatic, and volatile. This natural oils are mixtures of complex and volatile compounds produced as secondary metabolites by aromatic plants [44]. Essential oils are valuable not only for their natural protective function for host plants but also because they possess properties that are several times more potent than dried herbs. Antibacterial, antimicrobial, antiviral, and anti-fungal properties, as well as certain specific therapeutic effects, render essential oils a precious factor [45-53].

2. METHODOLOGY

This review has been conducted to investigate the antioxidant and antimicrobial activity of essential oils and plant extracts of the *ferula* species, and their potential for being utilized as the natural food preservative. All relevant databases were searched for the terms "*Ferula*", and "*Antioxidant*", "*Antiradical*", "*Antimicrobial*", "*Antibacterial*", and "*Antifungal*", without any publication date-related restriction up to 2021. However, it might be intriguing for readers to know that the oldest reference used was published in 1982. Information was collected through search using Scopus, Pubmed, Web of Science, Science Direct, Google Scholar databases, and related books and reliable websites, as well as prominent conferences and congresses.

3. RESULTS AND DISCUSSION

3.1 Chemical Composition and Biological Activities

Essential oils from aromatic and medicinal plants have shown biological activity and have attracted particular consideration [54]. The direct addition of aromatic plant essential oils and extracts to food products has been shown to have an antioxidant or antimicrobial impact [55]. Essential oils (also known as volatile oils) are aromatic oily liquids derived from plant materials (leaves, buds, fruits, flowers, herbs, twigs, bark, wood, roots, and seeds). The most popular technique for commercially extracting essential oils is steam or hydro-distillation, which was first introduced in the Middle Ages. Essential oils are complex natural mixtures containing anything from 20 to 60 different components in differing concentrations. Two or three main components are found at comparatively high concentrations (20–70%) in essential oils compared to other components present in trace quantities. Essential oils are chemically extracted from terpenes and their oxygenated derivatives, but different ingredients differ between various plant parts and plants [56,57].

Essential oils' hydrophobic nature can interact with the lipid membrane of bacteria, leading to increased permeability of cell constituents, which is compatible with other phenolic compounds [59-64]. Gram-positive bacteria are more

vulnerable than Gram-negative bacteria. Gram-negative bacteria's cell walls contain lipopolysaccharides that serve as a barrier to macromolecules and hydrophobic compounds, blocking active compounds in essential oils from reaching the cytoplasmic membrane [65,66]. Hydrophobicity is a property of essential oils and their constituents that allows them to partition with lipids found in the cell membranes of bacteria and mitochondria, making them more permeable by disrupting cell structures. This property inevitably contributes to the death of the bacterial cell leading to a massive number of vital molecules and ions escaping from the bacterial cell. The effectiveness of essential oils is determined by chemical composition, concentration, antimicrobial activity range matching with the target microorganism(s), interactions with the food matrix, and application process [67,68]. The combined effects of polyphenols adsorption to the bacterial cell membrane with membrane disruption and subsequent cellular contents leakage and the production of hydroperoxides from polyphenols are considered to be due to plant extracts' antimicrobial activity [69-72].

Plant extracts also have anti-fungal, antioxidant, and antimutagenic effects and the potential to suppress lipid oxidation in food [75-78].

Antioxidants are substances or compounds that avoid the production of free radicals by inhibiting the oxidation of other molecules in our bodies. Antioxidants' anti-inflammatory effects are responsible for most of their health benefits in the body [79]. An imbalance between increased levels of reactive oxygen species (ROS) and low antioxidant activity pathway is known as oxidative stress. Increased oxidative stress can cause damage to the cellular structure and even tissue loss. Free radicals can inflict oxidative

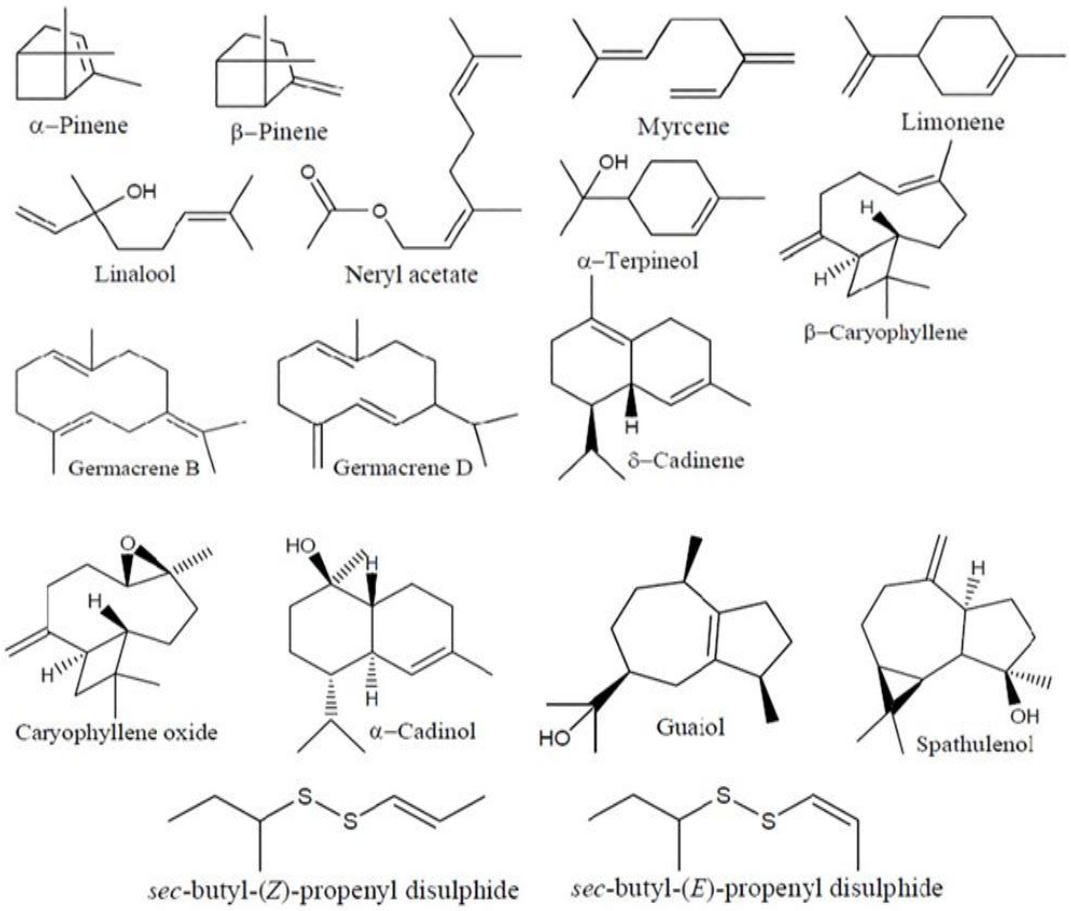

Fig. 2. Chemical structure of the most frequent main components present in the essential oils of *ferula* species [58]

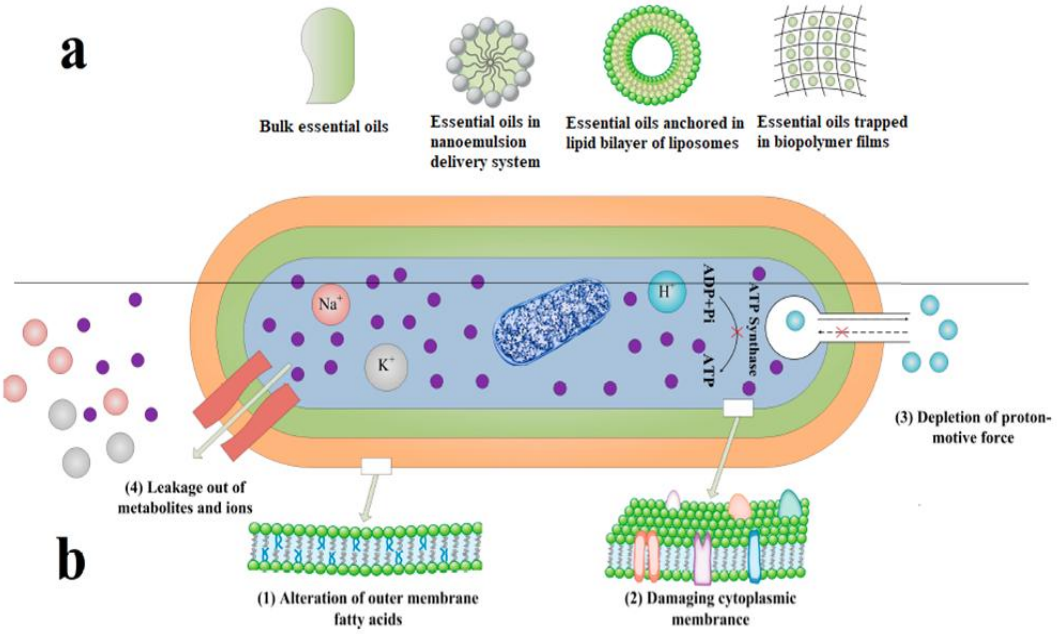

Fig. 3. (a) Bulk essential oils and different types of essential oil delivery systems, including nanoemulsion, liposomes, and biopolymer films; (b) Proposed common mechanisms of action and target sites of essential oils or essential oil delivery systems on bacterial cell [73,74]

damage to cellular structures, leading to a variety of chronic diseases. The ROS and reactive nitrogen species (RNS) have been identified as free radicals that cause oxidative damage. NO synthase and NAD(P)H oxidase isoforms, respectively, are closely regulated enzymes that produce ROS and RNS. ROS and RNS, such as superoxide, hydrogen peroxide, and singlet oxygen, as well as other free radicals, including nitrogen free radicals, are generated in the human body by a variety of internal and external conditions [80]. Antioxidants are also crucial in the petrochemical, food, cosmetics, and pharmaceutical sectors, where they are used to stabilize polymeric materials. Natural antioxidants present in foods are well recognized for their importance in protecting foods and presenting essential antioxidants in vivo. Antioxidants can significantly avoid or hinder lipid oxidation in foods, as well as autoxidation of pigments, flavors, proteins, and vitamins, even at low concentrations.

Antioxidants may work directly to scavenge ROS or indirectly to prevent them from being produced. On further oxidation, they can also scavenge the radical and create a new stable radical through intramolecular hydrogen bonding [81]. Since antioxidants cannot modify any oxidation that has already evolved, their effects can be powerful when these compounds are introduced early into fresh food items [82]. Various abiotic stresses cause plants to produce excessive amounts of reactive oxygen species (ROS), which are highly reactive and cause damage to proteins, lipids, carbohydrates, and DNA, resulting in oxidative stress. ROS is made up of free radicals ($O_2^{\bullet -}$, superoxide radicals; $OH^{\bullet}$, hydroxyl radical; $HO_2^{\bullet}$, perhydroxy radical and $RO^{\bullet}$, alkoxy radicals) as well as non-radical (molecular) forms (H_2O_2 , hydrogen peroxide and $^1O_2$, singlet oxygen) [83]. Carotenoids and phenolic compounds such as benzoic acid derivatives, flavonoids, proanthocyanidins, stilbenes, coumarins, lignans, and lignins are among the antioxidants found in plants consumed in the diet [66-68]. Primary antioxidants, such as phenolic compounds like -tocopherol, prevent or delay oxidation by scavenging free radicals. Secondary antioxidants work by trapping metal ions, scavenging reactive oxygen species (ROS), converting hydroperoxides to non-radical species, absorbing UV light, and deactivating singlet oxygen [84]. Some low-molecular-weight peptides derived from plant and animal sources have been shown to possess antioxidant and antimicrobial properties [85-87]. Enzymatic antioxidants and

Table 1. Some of the researches on antioxidant, antiradical, antimicrobial, antibacterial anti-fungal activity of *Ferula* species

Activity	Evaluation of the activity	Type of extract	Result / Conclusion	Reference
Antioxidant and antimicrobial activity	Nitric oxide scavenging, TBARS scavenging, as well as inhibitory concentration (IC50) were measured. Two food-borne Gram-negative bacteria, namely *Salmonella typhi* PTCC 1609 and *Escherichia coli* PTCC 1330, two food-borne Gram-positive bacteria, namely *Staphylococcus aureus* PTCC 1112 and *Bacillus subtilis* PTCC 1023, and two food-borne fungi, namely *Aspergillus niger* PTCC 5010 and *Candida albicans* PTCC 5027 were utilized for the test. H_2O_2 scavenging,	The air-dried oleo-gum-resins of the plants were dissolved in distilled water. The solution was subjected to hydro-distillation using an all-glass Clevenger type apparatus according to the method outlined by the British Pharmacopeia. The obtained essential oils were dried over anhydrous sodium sulphate.	Essential oils derived from the early stages of *F-asafoetida* growth may be used in the food industry as healthy and efficient natural antioxidants to increase the oxidative stability of fatty foods throughout storage. The essential oil derived from the later stages of *F-asafoetida* development maybe use as a safe and efficient source of antimicrobial agents in the health industry.	[90]
Antioxidant and antimicrobial activity	Reactive oxygen species (ROS), reactive nitrogen species (RNS), hydrogen peroxide (H_2O_2), and thiobarbituric acid reactive substances (TBARS) scavenging activities of *Carum* and *ferula* oils along with their antibacterial and anti-fungal activities against two Gram-negative bacteria (*Salmonella typhi* PTCC 1609 and *Escherichia coli* PTCC 1330), two Gram-positive bacteria (*Staphylococcus aureus* PTCC 1112 and *Bacillus subtilis* PTCC 1023), and two fungi (*Aspergillus niger* PTCC 5010 and *Candida albicans* PTCC 5027) were examined.	According to the British Pharmacopeia method, the air-dried seeds or the air-dried latex were dissolved in distilled water and hydrodistilled using an all-glass Clevenger type apparatus. The essential oil obtained was dried over anhydrous sodium sulphate.	Radical scavenging activity of *Carum* oil was higher than that of *Ferula* oil. Antibacterial and anti-fungal activities of Carum oil were higher than that *Ferula* oil. This study provides additional data supporting the use of *Carum* and *ferula* oil as an additive in foods against food burn pathogens. Besides, they could be used as a safe, effective, and easily accessible source of natural antioxidants to improve the oxidative stability of fatty foods during storage.	[91]
Antioxidant and antimicrobial activity	To determination of the antioxidant activity, Total phenolic content (TPC) assay, Total flavonoids content (TFC) assay, and DPPH radical scavenging assay were assessed. Separate tests were conducted using the dried leaf and gum extracts of *F. asafoetida* to determine their activity against *Escherichia coli* PTCC 1330, *Staphylococcus aureus* PTCC 1112, *Aspergillus niger* PTCC 5010, and *Saccharomyces cerevisiae* PTCC 5051 for the evaluation of the antimicrobial activity.	By adding 80 percent ethanol and stirring, hydroethanolic extracts of leaf and crude F-asafoetida gum were produced. The solvent was used in two cycles, and the ratio of solvent to dry leaf or fresh crude gum was 3:1 (w/w). The residue was obtained by evaporating the solvent under a vacuum after filtering.	It was revealed that leaf extract possesses more substantial antimicrobial properties against *E. coli*, *S. aureus*, and *S. cerevisiae* than gum extract. *Ferula asafoetida* extracts can have particular applications in the food industry due to beneficial biological activity.	[92]
Antioxidant and antimicrobial activity	The essential oil from the seeds of the endemic Tunisian plant *ferula tunetana* Pomel ex Batt. was assessed for antimicrobial, antioxidant, and antigerminative properties. The isolated oil wastested also for its	On a Clevenger-type apparatus, the fresh seeds were subjected to hydro-distillation. The essential oil was	Antimicrobial activity against *Salmonella typhimurium* LT2 DT104 and *Bacillus cereus* ATCC14579 was indicated.	

Activity	Evaluation of the activity	Type of extract	Result / Conclusion	Reference
	antioxidant activity against DPPH, ABTS, $O_2^{\cdot}$ and H_2O_2. Isolated oil was tested for its antimicrobial activity using the disc-diffusion and the microdilution assays against six Gram-positive (*Staphylococcus epidermidis* CIP 106510, *Staphylococcus aureus* ATCC 25923, *Micrococcus luteus* NCIMB 8166, *Bacilluscereus* ATCC 11778, *Bacillus cereus* ATCC 14579, *Bacillus subtilus* ATCC 6633) and five Gram-negative bacteria (*Escherichia coli* ATCC 35218, *Escherichia coli* ATCC 25922, *Pseudomonas aeruginosa* ATCC 27853, *Salmonella typhimurium* LT2DT104, *Salmonella typhimurium* ATCC 13311) as well as towards two Candida species (*Candida albicans* ATCC 90028 and *Candida glabrata* ATCC 90030).	decanted and dried using sodium sulfate as a drying agent.	However, it exerted a moderate antioxidant activity against H_2O_2 and $O_2^{\cdot}$.essential oil of *F. tunetana* could be used as bactericidal and fungal alternatives to antibiotics against the microorganisms.	[93]
Antioxidant and antimicrobial activity	The antimicrobial and antioxidant activities of the aerial parts of *ferula caspica* M. Bieb. extracts were examined. CUPRAC, ABTS, FRAP, Folin–Ciocalteu, and aluminum chloride methods were measured by the antioxidant capacities. The extracts were tested against the bacteria (*Escherichia coli* ATCC 25922, *Enterococcus faecalis* ATCC 29212, *Pseudomonas aeruginosa* ATCC 27853, *Staphylococcus aureus* ATCC 29213) and fungal species (*Candida albicans* ATCC 90028, *C. krusei* ATCC 6258, *C. parasilosis* ATCC 90018) for antimicrobial activity.	Air-dried and powdered aerial parts of *F. caspica* were extracted with chloroform and methanol, using a rotary extractor without vacuum. The methanol extract was partitioned between ethyl acetate and water.	Isolation studies were performed on chloroform, and ethyl acetate extracts showed the highest activity in the assays for antimicrobial and antioxidant activities, respectively.	[94]
Antioxidant and antimicrobial activity	The chemical composition and biological activity of the essential oil from the underground parts of *ferula tadshikorum* M. Pimen, collected from the southern part of Tajikistan, were evaluated. The antioxidant activity of the essential oil was evaluated by 2,2-diphenyl-1-picrylhydrazyl (DPPH), 2,2′-azino-bis-[3-ethylbenzthiazoline-6-sulfonic acid] (ABTS), and ferric reducing antioxidant power (FRAP) assays. The essential oil was screened against methicillin-resistant *Staphylococcus aureus* (MRSA) NCTC 10442 and *Escherichia coli* ATCC 25922 bacteria.	The fresh samples from the underground parts of *F. tadshikorum* were cut into small pieces and hydrodistilled to give the yellow essential oil.	The chemical compositions of the essential oil were dominated by the sulfur-containing compounds (Z)-propenyl sec-butyl disulfide, (E) propenyl sec-butyl disulfide, and (E)-1(1-propen-1-yl)-2(2-thiopent-3-yl) trans disulfide. The essential oil of F. tadshikorum exhibited low antioxidant activity compared to the positive control, caffeic acid. The essential oil has weak antioxidant and antimicrobial activities, similar to other sulfur-containing ferula oils.	[95]
Antioxidant activity	Chemical composition and antioxidant activity of essential oil and methanolic extracts of *ferula microcolea* analyzed by gas chromatography and gas chromatography/mass spectrometry. DPPH assay, β-Carotene/linoleic acid bleaching assay, Total Phenolics Assay, and Total Flavonoid Content were assessed for the antioxidant	Dry aerial parts of *ferula microcolea* were subjected to the hydro-distillation using a Cleavenger-type apparatus, according to the method recommended by the European	*Ferula microcolea* methanol extracts have a greater antioxidant function than the essential oil. *Ferula microcolea* methanol extracts could be used instead of more toxic synthetic antioxidants in foods,	[96]

Activity	Evaluation of the activity	Type of extract	Result / Conclusion	Reference
	evaluation.	Pharmacopia to produce oils. The obtained essential oils were dried over anhydrous sodium sulphate.	pharmaceuticals, and cosmetic formulations.	
Antioxidant activity	The antioxidant efficacy of aerial parts extracts of *ferula communis* L.was evaluated using different experimental models, including total phenolic contents, total flavonoid contents, ABTS radical scavenging assay, DPPH radical scavenging assay, Oxygen Radical Absorbance Capacity assay, Ferric reducing power, Metal-chelating power, as well as In vitro evaluation of antioxidant capacity.	Sample extracts (flower, fruit, and stem) were obtained by stirring dry organs powder in methanol using a magnetic stirrer plate. Extracts obtained were filtered through a Whatman filter paper and freed of solvent under reduced pressure, using a rotary evaporator.	While in vitro classic assays, as well as in vitro cellular models, have shown that *F. communis* extracts have strong antioxidant properties, the antioxidant actions of organs ranged greatly. Flower extracts had the largest antioxidant capacities and the highest overall phenolic content. These findings suggested that this organ has a lot of potentials as a source of beneficial phenolic compounds and as a potential source of health products for the pharmaceutical industry.	[97]
Antioxidant activity	Antioxidant activity of the methanol extract of the aerial parts of *ferula assafoetida* was determined by employing various in vitro assay systems, including total phenolic compounds and flavonoid content, DPPH radical-scavenging activity, reducing power, nitric oxide-scavenging activity assay, metal chelating activity, as well as ferric thiocyanate method.	Using a British-style Clevenger apparatus, the air-dried and ground, aerial parts of the plant was subjected to water distillation. After filtration, the essential oil was dried over anhydrous sodium sulphate.	In all of the models tested, the aerial parts of the extract of *F. assafoetida* had high but varying amounts of antioxidant activity. The extracts had strong Fe^{2+} chelating, DPPH radical scavenging, and nitric oxide scavenging properties.	[98]
Antioxidant activity	The chemical composition and antioxidant properties of *ferula-assa-foetida* leaves essential oil were determined. For antioxidant activity, diphenyl picrylhydrazyl was used to evaluate the samples' radical scavenging behavior (DPPH). The total antioxidant potential was determined using the phosphomolybdate process. Folin-Ciocalteu and Zhishen methods were used to determine the sum of overall phenol and flavonoid. Gas chromatography/mass spectrometry (GC/MS) was also used to examine the components of FLEO.	The yellow oil was obtained by hydro-distilling the leaves using a Clevenger apparatus. Anhydrous sodium sulfate was used to dry the crude.	The essential oil of *ferula assa-foetida* leaf is a readily available source of natural antioxidants such as eremophilene, δ-cadinene, and longiborneol, and it may be ideal for use in food and medicinal applications, as well as an excellent substitute to mitigate the risk of atherosclerosis, coronary heart disease, and other free radical-related health issues.	[99]
	The *in vitro* and *in vivo* antioxidative and radical scavenging potential of organic extracts of the aerial parts and roots of *ferula szovitsiana* DC	Dried powder of aerial parts or roots (stems, leaves, flowers, and fruits) of	The *F. szovitsiana* extracts show relevant antioxidant activity both *in vitro* and *in*	

Activity	Evaluation of the activity	Type of extract	Result / Conclusion	Reference
Antioxidant activity	(Umbelliferae) were evaluated by ferric reducing antioxidant power (FRAP) and 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical scavenging activities *in vitro*. The influence of the most potent sample was examined in rats for the prevention of plasma and liver lipid peroxidation and activity of antioxidant enzymes catalase (CAT) and superoxide dismutase (SOD).	*F. szovitsiana* was extracted serially with hexane, diethyl ether, ethyl acetate, and methanol. The extraction was repeated three times, and the solvent was evaporated in a vacuum.	*vivo* by means of scavenging free radicals, reducing the cellular lipid peroxidation, and increasing the activity of antioxidant enzymes and total antioxidant power. The higher antioxidant potential of methanol extract of *F. szovitsiana* shown in the current study indicates that most of the active constituents of this plant are polar phenolic components.	[100]
Antioxidant activity	Antioxidant and antihaemolytic activities of *ferula foetida regel (Umbelliferae)* were evaluated. 1,1-Diphenyl-2-picryl hydrazyl radical (DPPH), nitric oxide and H_2O_2 scavenging activities, Fe^{2+} chelating ability, reducing power, and hemoglobin-induced linoleic acid peroxidation were used to evaluate antioxidant activities. Total phenolic compounds were determined as gallic acid equivalents, and total flavonoid contents were calculated as quercetin equivalents from a calibration curve.	A known amount of each sample was extracted at room temperature by percolation with ethanol/water. The extract was then separated from the sample residue by filtration through a Whatman filter paper. This procedure was repeated thrice. The resulting extract was concentrated over a rotary vacuum until a crude extract was obtained.	Excellent antioxidant and antihemolytic activities in the hydroalcoholic extract of *ferula foetida regel* Boiss flower, stem, and leaf were highlighted, resulting from their high phenol and flavonoid contents.	[101]
Antioxidant activity	To evaluate the antioxidant activity of various solvent extracts and essential oil of *ferula orientalis* L. various *in vitro* assays approaches, including total phenolic and total flavonoid contents and DPPH and ABTS radical scavenging activity assays, as well as some *in vitro* assays were examined.	The stems of the plant were washed and crushed into small pieces with a blender. Water, ethanol, and methanol extracts were prepared by using ultrasonic and classical methods, and essential oil was obtained by the hydro-distillation method.	Compared to ultrasonic and classical water, ethanol:water, and methanol:water samples, the essential oil of *F. orientalis* had a moderately high antioxidant function. The total phenolic and total flavonoid contents of the extracts were measured at high concentrations, especially in the methanol:water extract.	[102]
Antioxidant activity	The antioxidant potential of dierent *ferula* species, *F. caratavica*, *F. kuchistanica*, *F. pseudoreoselinum*, *F. samarcandica*, *F. tenuisecta* and *F. varia*, was assessed in vitro using different assays including 2,2'-azino-bis (3-ethylbenzothiazoline-6-sulphonic acid (ABTS), cupric reducing antioxidant capacity (CUPRAC), ferric reducing power (FRAP) and phosphomolybdenum (PM) assays.	All the plant materials were air-dried in the shade and powdered using a mortar and pestle to get particles of a uniform, reduced size. Preparation of the essential oil samples was achieved by hydro-distillation of the air-dried aerial parts of the different *ferula* species by Clevenger-type	The essential oils obtained from different *ferula* species, *F. caratavica*, *F. kuchistanica*,*F. pseudoreoselinum*, *F. samarcandica*, *F. tenuisecta* and *F. varia* showed significant variation as revealed by GC analyses. the different *ferula* species could serve as a promising natural antioxidant drug that could be	[103]

Activity	Evaluation of the activity	Type of extract	Result / Conclusion	Reference
		apparatus. Anhydrous Na_2SO_4 was used to dehydrate the prepared essential oils	included in different products and used as spices to alleviate hyperglycemia and as a natural ingredient in pharmaceutical cosmetics to counteract hyperpigmentation.	
Antioxidant activity	The antioxidant property of the extracts of *ferula elaeochytris* and *Sideritis stricta* was determined by evaluating the total phenolic and flavonoid contents, β-carotene/linoleic acid assay, DPPH free radical scavenging assay, ABTS cation radical scavenging assay, cupric-reducing antioxidant capacity (CUPRAC) assay, and metal chelating assay.	The aerial parts of *F. elaeochytris* were extracted separately with different solvents according to their increasing polarity: hexane, acetone, and methanol. The water extract was obtained by lyophilization using a freeze-drier.	The methanol and water extracts of *F. elaeochytris* and the acetone and methanol extracts of *S. stricta* containing the highest amount of total phenolic and flavonoid contents showed the highest antioxidant activities in β-carotene–linoleic acid, DPPH•, ABTS•+ , and CUPRAC assays. *Ferula* and *Sideritis* species have promising activities and high phytochemical contents. They could be used as a potential source of natural antioxidants in the food, cosmetic, and pharmaceutical industries.	[104]
Antibacterial activity	Chemical composition and antimicrobial activity of the essential oils of aerial parts of *ferula latisecta* and *Mozaffariania insignis*, which are endemic to Iran, were evaluated. The Gram-positive bacteria included *Staphylococcus aureus* ATCC 25923, *Enterococcus faecalis* ATCC 15753, and *Bacillus subtilis* ATCC 9372, and the Gram-negative bacteria included *Klebsiella pneumoniae* ATCC 3583, *Pseudomonas aeruginosa* ATCC 27852, and *Escherichia coli* ATCC 9763 were used for antimicrobial evaluation.	Aerial parts of *F. latisecta* and *M. insignis* were subjected to hydro-distillation using a Clevenger-type apparatus to produce light yellow oils.	The essential oil of *F. latisecta* has no impact on *Pseudomonas aeruginosa*, but showed substantial activity against both Gram-positive bacteria and *Escherichia coli*. *M. insignis* essential oil had the highest inhibitory efficacy against *Staphylococcus aureus* and demonstrated significant activity against *Escherichia coli* and *Bacillus subtilis*, but was ineffective against *Klebsiella pneumoniae*, *Pseudomonas aeruginosa*, and *Enterococcus faecalis*.	[105]
Antibacterial activity	*Ferula gummosa* Boiss. (Apiaceae) fruit volatile oil in vitro antimicrobial activities were determined by the agar disc diffusion method. Gram positive bacteria (*Staphylococcus aureus*, *S. epidermis*, and *Bacillus subtilis*), three strains of Gram negative bacteria (*Escherichia coli*, *Salmonella typhi*, and *Pseudomonas aeruginosa*), and two strains of fungi (*Candida albicans* and *C. kefyr*) were used for the antimicrobial	*F. gummosa* . Boiss fruits were collected from wild plants. Air-dried fruits were powdered and subjected to hydro-distilation using a Clevenger-type apparatus.	The bacteriostatic and fungistatic properties of the oil are suspected to be associated with the high a-pinene and b-pinene content. The results indicate that the fruits have the potential for use as an aromatic antimicrobial agent.	[106]

Activity	Evaluation of the activity	Type of extract	Result / Conclusion	Reference
	test.			
Antibacterial activity	Content of polysulphides in the volatile oil of *ferula latisecta* Rech. F. et Aell. fruits and antimicrobial activity of the oil were analyzed by GC/MS. For antimicrobial evaluation, five microorganisms, including *Staphylococcus aureus* ATCC6538p and *Bacillus cereus* ATCC10876 as gram-positive bacterial species, *Pseudomonas aeruginosa* ATCC 9027 and *Escherichia coli* ATCC 10536 as gram-negative bacterial species, and *Candida albicans* ATCC 10231 as a fungal strain were used.	Air-dried fruits of the plant were powdered, and the oil was obtained by hydro-distillation using a Clevenger-type apparatus. The oil was separated from the aqueous layer, dried over anhydrous sodium sulfate.	The volatile oil from *F. latisecta* possesses moderate antibacterial activity against *Staph.aureus* and relatively strong anti-fungal activity against *C.albicans*. The major component of the oil of the fruits of *F.latisecta* was sec-butyl-(Z)-propenyl disulphide.	[107]
Antibacterial activity	Gas chromatography-mass spectroscopy (GC/MS) was used to examine the essential oil of the aerial part of *ferula assa-foetida*. Using the microdilution process, the essential oil's minimum inhibitory concentrations were investigated against Gram-positive bacteria, namely *Staphylococcus epidermidis*, *Staphylococcus aureus*, *Bacillus subtilis* and Gram-negative bacteria, namely *Escherichia coli*, *Pseudomonas aeruginosa*, *Klebsiella pneumonia*.	Hydrodistillation was used on air-dried flowering aerial parts, and the oil was dried over anhydrous sodium sulfate.	The disulphide compounds were the main constituents of the essential oil of *F-assa-foetida* L- from the Neishabour mountains (Iran) among the different compounds found in the oil. Disulphide compounds may be the source of this plant's mild antibacterial effect, according to other studies from around the country.	[108]
Antibacterial activity	Antibacterial activity of the different extracts of *F. asafoetida* was determined by the disc diffusion method and various bacteria including *Escherichia coli*, *Staphylococcus aureus*, *Klebsiella pneumoniae*, *Shigella flexneri*, and *Enterococcus faecalis*.	Both the red and white type of *ferula asafoetida* were firstly dried and then grinded to powder. Then both powdered forms were suspended in autoclaved distilled water. Similarly, the extracts in hot water, hexane, ethanol, and petroleum ether were prepared.	The extracts of *F. assafoetida* demonstrated activity against both gram-positive and gram-negative bacteria. However, *enterobacters* were found to be more susceptible. Organic extracts have shown more potent activity in comparison to aqueous extracts.	[109]
Antibacterial activity	The antibacterial effect of the aerial parts and root essential oils of *F. haussknechtii* were separately tested against 9 bacteria, naming *Bacillus cereus* PTCC 1015, *Escherichia coli* ATCC 25922 , *Bacillus pumilus* PTCC 1274, *Bacillus subtilis* ATCC 465, *Klebsiella pneumoniae* ATCC 10031, *Enterococcus faecalis* ATCC 29737, *Staphylococcus aureus* ATCC 25923, *Staphylococcus epidermidis* ATCC12228, and *Pseudomonas aeruginosa* ATCC 85327. The antibacterial activity of essential oils was determined via the disk diffusion method.	By using Clevenger and distillation with water, the essential oils of aerial parts and root of *ferula haussknechtii* were isolated	Both essential oils have antibacterial effects on *Staphylococcus aureous*, *Staphylococcus epidermidis*, and *Bacillus pumilus*. By considering *F. haussknechtii* compounds and the antibacterial effect of its essential oils, it can be used in pharmaceutical and food industry.	[110]
Antimicrobial activity	Screening of anti-fungal properties of many organic and aqueous extracts of Asafoetida against Gram positive bacteria, namely	Asafoetida powder and asafoetida crude form each was dissolved in the	Ethanol extract of asafoetida powder form was found to be more effective than other	[111]

Activity	Evaluation of the activity	Type of extract	Result / Conclusion	Reference
	Staphylococcus aureus MTCC 3160 and *Bacillus subtilis* MTCC 441, and Gram negative bacteria, namely *E.coli* MTCC 443 and *Pseudomonas aruginosa* 4673 was carried out.	ethanol (95%), Acetone, Petroleum ether, a mixture of Carbon tetrachloride, and methanol. Then Soxhlet extraction was run. All extracts were concentrated by evaporating the solvent.	extracts. Solvents containing asafoetida powder were tested against test organisms and found to have no inhibition zone against any of them.	
Antimicrobial activity	Antimicrobial activities of Asafoetida resin extracts were measured with the help of *E.coli* MTCC-443, *Pseudomonas aeruginosa* MTCC4673, *Staphylococcus aureus* MTCC3160, *Bacillus subtilis* MTCC-441, *Aspergillus niger* MTCC-1344.	The crude form of Asafoetida was crushed into a fine powder with the pestle and mortar. Then the crude (resin) form of Asafoetida was dissolved in ethanol, petroleum ether, acetone, carbon tetrachloride, methanol, and aqueous extracts were prepared.	*B. subtilis*, *S. aureus*, *E. coli*, *P. aeruginosa*, and *Aspergillus niger* were all eliminated by alcoholic and aqueous extracts of Asafoetida.	[112]
Antimicrobial activity	Fungal strains *Aspergillus flavus* MTCC 277, *Aspergillus niger* MTCC281, *Aspergillus ochraceus* MTCC 4643, *Fusarium oxysporum* MTCC 1755 and *Penicillium chrysogenum* MTCC 161 and bacterial strains *Staphylococcus aureus* MTCC 7443, *Yersinia enterocolitica* MTCC 859, *Salmonella typhi* MTCC 80, *Salmonella paratyphi* MTCC537, *Bacillus cereus* MTCC 1305, *Bacillus subtilis* MTCC 441, *Listeria monocytogenes* MTCC 657, *Escherichia coli* MTCC 118 were used for the evaluation of the antimicrobial activity of volatile oils from *ferula* asafoetida varieties.	Pathani and Irani oleo gum resins were hydrodistilled using Clevenger apparatus. The volatile distillates were collected and dried over anhydrous sodium sulphate.	Variations in chemical composition between the varieties of asafoetida were well demonstrated, due to which Pathani oil resulted in being an antibacterial agent while Irani to be a fungicidal agent. The variation in the constitution of active components present in the two varieties and their potential in pharmaceutical uses and food preservation was illustrated.	[113]
Antimicrobial activity	Chemical composition and antimicrobial activity of essential oil obtained from stem/leaves and flowers/fruits of *ferula szovitsiana D.C.* were analyzed by GC and GC–MS. The antimicrobial and anti-fungal activities of the equal mixture of essential oils from stem/leaves and flowers/fruits were determined against *Bacillus subtilis* (ATCC 12711), *Staphylococcus aureus* (ATCC 29737), *Echerichia coli* (ATCC 8739), *Pseudomonas aeruginosa* (ATCC 9027), *Aspergillus niger* (ATCC16404) and *Candida albicans* (ATCC 14053).	The aerial parts of *ferula szovitsiana* (stem/leaves and flowers/ fruits) were dried and subjected to hydro-distillation, using a Clevenger-type apparatus. The essential oil preparation from each part was performed three times, and oils were dried with anhydrous sodium sulphate.	The essential oil of *F. szovitsiana* represents the most potent antimicrobial candidates for *Bacillus subtilis*. However, the essential oil of the plant exhibited weaker activity against other Gram-positive bacterial strains tested, and in particular against Gram-negative bacterial or fungal strains, even at a high concentration.	[114]
Antimicrobial activity	The chemical composition and biological activity of *ferula aucheri* essential oil were investigated. Nine bacterial strains including *Pseudomonas aeruginosa* (ATCC 27853), *Bacillus subtilis* (ATCC 6633), *Escherichia coli* (ATCC 10536), *Staphylococcus aureus* (ATCC	The shade-dried flowering tops, fruits, and roots of *F. aucheri* were ground and each powder was subjected to hydro-distillation at normal pressure	Root and fruit oils were more effective than gentamicin against *Escherichia coli,* and flowering tops oils proved lower MICs versus *Staphylococcus aureus*. The	[115]

Activity	Evaluation of the activity	Type of extract	Result / Conclusion	Reference
	29737), *Klebsiella pneumonia* (ATCC 10031), *Staphylococcus epidermidis* (ATCC 12228), *Shigella dysenteriae* (PTCC 1188), *Proteus vulgaris* (PTCC 1182), *Salmonella paratyphi* A- serotype (ATCC 5702), as well as two fungus including *Aspergillus brasiliensis* (ATCC 5011) and *Aspergillus niger* (ATCC 16404), and a yeast, *Candida albicans* (ATCC 10231) were used for evaluation of the antimicrobial activity.	using a Clevenger- type apparatus. The essential oils were collected, dehydrated over anhydrous sodium sulfate.	essential oils of *F. aucheri* were found to have antimicrobial properties as well as inhibition properties against acetylcholine esterase enzyme.	
Antimicrobial activity	The composition, antibiofilm, and antimicrobial activities of essential oil of *ferula* assa-foetida oleo-gum-resin were assessed. *Candida albicans*, *C. dubliniensis*, *C. glabrata*, *C. krusei* , *C. tropicalis*, *Cryptococcus neoformans*, *Aspergillus flavus*, *A.fumigatus* , *A. oryzae*, *A. clavatus*, *Pseudallescheria boydii*, *Penicillium marneffei* and *Exophiala dermatitidis* , as well as *Microsporum gypseum*, *M. canis* and *Trichophyton rubrum* were used for the determination of anti-fungal activity. The antibacterial activities of the essential oils were tested against standard strains of *Staphylococcus aureus*, *Streptococcus mutans*, *S. sanguis*, *Enterococcus faecalis*, *Bacillus cereus, Escherichia coli*, *Pseudomonas aeruginosa*, and clinical isolates of *Listeria monocytogenes*, *S. aureus*, *S. mutans*, *E. coli* and *P. aeruginosa*.	The air-dried oleo-gum resin of *F.assa-foetida* was hydrodistillated, using a Clevenger-type apparatus, based on the method outlined by the British Pharmacopoeia. The obtained oils were dried over anhydrous sodium sulfate.	The essential oil of *F. assa-foetida* has a considerable antimicrobial activity against some bacterial and fungal species. As the industries tend to use natural preservatives instead of chemical additives in their products, the essential oil of F. assa-foetida with potential antimicrobial activities might be considered as a proper natural source to control bacterial and fungal contaminations in the products and improve their shelf life and quality.	[116]
Antimicrobial activity	antibacterial and anti-fungal activity of extracts of Asafoetida was measured. For antibacterial activity *Bacillus subtilis*, *Staphylococcus aureus*, *Klebsiella pneumonia*, *Escherichia coli*, and for anti-fungal activity *Aspergillus niger*, *Candida albicans* were selected.	The powdered plant material was extracted in the various extracts, namely chloroform, ethyl acetate, ethanol, methanol, and water. Extraction was carried out at room temperature, filtered, and evaporated to dryness under reduced pressure in a rotary evaporator.	The antimicrobial and anti-fungal efficacy of ethyl acetate, ethanol, and methanol extracts is significant, with methanolic extract having the highest activity.	[117]
Antimicrobial activity	The antimicrobial and cytotoxic activities of isolates obtained from the underground parts of the Balkan endemic plant *ferula heuffelii* Griseb. ex Heuff. were assessed. the Gram-positive bacteria *Staphylococcus aureus* (ATCC 25923), *S. epidermidis* (ATCC 12228), *Micrococcus luteus* (ATCC 3341), *Enterococcus faecalis* (ATCC 29212), and *Bacillus subtilis* (ATCC6633), the Gram-negative bacteria *Escherichia coli* (ATCC25922 and ATCC 10536), *Klebsiella pneumoniae* (NCIMB 9111 and ATCC13883), and *Pseudomonas aeruginosa* (ATCC 27853), and one strain of the yeast *Candida albicans* (ATCC 10231) were used for antimicrobial activity.	The underground parts of *ferula heuffelii* were collected. Air-dried plant material was powdered and then macerated, first with $CHCl_3$ and then with MeOH. The extracts were then filtered, and the solvents evaporated.	The $CHCl_3$ and MeOH extracts exhibited moderate antimicrobial activity, more pronounced against Gram-positive than Gram-negative bacteria, especially against Staphylococcus aureus and Micrococcus luteus.	[118]

Activity	Evaluation of the activity	Type of extract	Result / Conclusion	Reference
Antimicrobial activity	The essential oils from the leaves and stems of *ferula szowitsiana* DC. (Umbelliferae) were separately obtained and then analyzed by GC and GC/MS methods. The antimicrobial activity of the leaf oil was tested via in-vitro microdilution broth technique. Antibacterial activity was assessed by *Escherichia coli*, *Pseudomonas aeruginosa*, *Proteus vulgaris*, *Salmonella typhimurium*, *Staphylococcus epidermidis*, *Methicillin-resistant Staphylococcus aureus,* and *Candida albicans*.	Air-dried leaves and stems of *F. szowitsiana* were separately hydrodistilled using a Clevenger-type apparatus to yield oils. The oils were dried over anhydrous sodium sulphate.	The findings suggest that the leaf oil of *F. szowitsiana* may be used as an aromatic antimicrobial agent against a variety of pathogenic bacteria.	[119]
Antimicrobial and antiradical activity	The composition, antimicrobial, antiradical, and spasmolytic activity of *ferula heuffelii* Griseb. ex Heuffel (Apiaceae) essential oil were assessed. Gram positive bacteria *Staphylococcus aureus* (ATCC 25923), *Staphylococcus epidermidis* (ATCC 12228), *Micrococcus luteus* (ATCC 3341), *Micrococcus flavus* (ATCC 10240), *Enterococcus faecalis* (ATCC29212), *Bacillus subtilis* (ATCC 6633), and Gram negative bacteria *Escherichia coli* (ATCC25922), *Klebsiella pneumoniae* (ATCC 13883), *Pseudomonas aeruginosa* (ATCC 27853), and two strains of a yeast *Candidaalbicans* (ATCC 10259 and ATCC 10231) were used for evaluation of the antimicrobial activity. 2,2-diphenyl-1 picrylhydrazyl radical (DPPH) was also used for the radical scavenging activity evaluation.	Air-dried underground parts were powdered, and the essential oil was isolated by hydro-distillation in a Clevenger-type apparatus according to the procedure of the European Pharmacopoeia, using n-hexane as a collecting solvent.	Two strains of *Candida albicans* and *Micrococcus luteus*, *Staphylococcus epidermidis*, *Bacillus subtilis*, and *Micrococcus flavus* showed the highest vulnerability against the antimicrobial activity of the essential oil. Scavenging of DPPH radical. However, it was concentration-dependent	[120]
Anti-fungal activity	Essential oils derived from spices were investigated for their anti-fungal activity against *Aspergillus niger*, *Candida albicans*, *Candida blanki*, *Candida cylindracea*, *Candida glabrata*, *Candida krusei*,*Candida tropicalis*, and *Saccharomyces cerevisiae* using the disc diffusion method.	The essential oils of 20 spices, including asafoetida, were tested.	All fungal strains were inhibited by asafoetida oil, but *Candida tropicalis*, *Candida albicans*, *Saccharomyces cerevisiae*, and *Aspergillus niger* experienced the most inhibitory action.	[121]
Anti-fungal activity	Essential oils extracted from the seeds of neem (*Azadirachta indica*), mustard (*Brassica campestris*), black cumin (*Nigella sativa*), and asafoetida (*Ferula assafoetida*) were evaluated for their anti-fungal activity against eight seed borne fungi, *Aspergillus niger*, *A. flavus*, *Fusarium oxysporum*, *F. moniliforme*, *F. nivale*, *F. semitectum*, *Drechslera hawiinesis* and *Alternaria alternata*. Ridomyl gold was used for comparison.	Seeds of mustard (*Brassica campestris*), black cumin (*Nigella sativa*), neem (*Azadirachta indica*), and Asafoetida (*Ferula asafoetida*) were ground into a fine powder in an electric grinder, and oils were extracted with n-hexane on Soxhlet's extraction apparatus.	Regarding *A. flavus* and *Nigella sativa*, asafoetida oil at 0.1% and 0.15% significantly inhibited the growth of all test fungi. All oils were more effective and well compared to fungicide except mustard oil. Our data on the anti-fungal properties of oils suggest that these oils should be examined further to evaluate their potential as a natural fungicide.	[122]
Anti-fungal activity	Ninety formulations of neem oil (*Azadirachta indica*), and *ferula asafoetida*, were screened *in vitro* against *Sclerotium rolfsii* ITCC 5226 and *Macrophomina phaseolina* ITCC 0482.	Different formulations of neem oil, and *ferula asafoetida* test samples were prepared in acetone.	Anti-fungal behavior was observed in formulations containing *F. asafoetida* as a natural ingredient.	[123]

Activity	Evaluation of the activity	Type of extract	Result / Conclusion	Reference
Anti-fungal activity	The anti-fungal and allelopathic effects of the methanol extracts concentrations against *T. harzianum* and *Pleurotus* spp., were investigated in dual culture experiments	A sample of oleogum-resin was macerated with 96% (v/v) methanol. The sample was filtered and concentrated in a rotary evaporator under reduced pressure. The dried methanol extract was dissolved in dimethyl sulfoxide.	At higher concentrations, asafoetida demonstrated fungicidal activity against *T. harzianum* strains and *Pleurotus spp*.	[124]
Anti-fungal activity	Anti-fungal effects of asafoetida seed essential oil on in vitro growth of five species of plant pathogenic fungi namely, *Bipolaris sorokiniana*, *Verticellium. Sp*, *Fusarium graminearum*, *Fusarium solani* and *Aspergillus niger* were assessed.	Clevenger apparatus used for seed essential oil extraction.	The growth of *Bipolaris sorokiniana* has been pretty much stopped. With an increase in essential oil concentration, the growth of other species improved as well.	[125]
Anti-fungal activity	Anti-fungal activity of *in vitro* aqueous and alcoholic extracts of Barije root (*Ferula gummosa*) was evaluated against *Candida albicans* (PTCC 5027), *Trichophyton rubrum* (PTCC5143), and *Aspergillus fumigatus* (PTCC 5009).	The plant was dried in the dark, and aqueous, alcoholic extracts of its root powder were prepared using the Soxhlet method.	Methanol and ethanol extracts proved to have anti-fungal activity against *Candida albicans* yeast *in vitro,* while the fungi of *Aspergillus fumigatus* and *Trichophyton rubrum* had no sensitivity to these types of extracts.	[126]
Anti-fungal activity	Composition and anti-fungal activity of the oil of *ferula gummosa* samples from Iran were evaluated. Strains of the *Colletotrichum gleosporoides*, *Botrytis cinerea*, *Fusarium verticillioides* and *Aspergillus niger* were used for the determination of the anti-fungal activity.	The fruits of three samples of *F. gummosa* Boiss. were powered separately and subjected to hydro-distillation, using a Clevenger-type apparatus. The oils were dried over anhydrous sodium sulphate.	The anti-fungal compounds of samples assayed are not well known; however, the amount of some components might determine the level of toxicity for the fungus.	[127]

non-enzymatic antioxidants are the two primary categories of natural antioxidants. Primary and secondary enzymes make up the enzymatic antioxidants. Glutathione peroxidase, superoxide dismutase, and catalase are the main enzymes that catalyze the direct decomposition of ROS species to inactive compounds, while glutathione reductase and glucose-6-phosphate dehydrogenase are secondary enzymes. The glutathione reductase converts oxidized glutathione to its reduced state, allowing further free radicals to be neutralized. NADPH is produced by glucose-6-phosphate, which does not instantly neutralize free radicals but can stimulate other endogenous antioxidants [88]. Non-enzymatic antioxidants scavenge peroxy or alkoxy radicals, quench singlet oxygen, and eliminate pro-oxidative transition metal pollutants. A category of natural substances known as antioxidants includes simple phenols, phenolic acids, polyphenolic derivatives, amino acids, tocopherols, and ascorbic acid (vitamins E and C, respectively) [89].

In the food industry, antioxidants and antimicrobials should be used extensively to inhibit microbial growth in foods, as well as to prevent the degradation of fats from preventing rancidity. Nonetheless, growing concern about the adverse effects of synthetic antioxidants and antimicrobials on consumers' health, as well as the benefits of natural compounds, has triggered further scientific experiments into the mechanism of action and toxicity of natural antioxidants and antimicrobials. As shown in table1, among various tested natural antioxidants and antimicrobials, those derived from *ferula* species have appealed quite an interest. Although the method of isolation of compounds with biological activity, as well as part of the plant used for isolation, growth-stage of the plant, and some other contributing factors can affect the antioxidant and antimicrobial activities of plant extracts and essential oils, on the whole, it can be deduced that different species of *ferula* are potential sources of natural food preservative compound.

4. CONCLUSION

Food safety is a significant concern for both consumers and the food industry, so specific preservative agents with significant antimicrobial and antioxidant properties have been used on food products to make them safer and protect them from oxidation and food-borne pathogens. Food researchers and the food industry have been encouraged to develop novel and more efficient natural products due to today's consumer preference for natural preservatives over synthetic additives. Aside from the current ones, there are undoubtedly many more natural herbal, animal, or microbial additive ingredients that have yet to be found. One of the plants studied in various research, *ferula*, has been approved to have promising antibacterial, anti-fungal, and antioxidant activity; hence, essential oils and plant extracts of *ferula* species can be used as a potential natural preservative. There are challenges for the industrial application of *ferula*, and the first one is cultivation. As this plant is wild-flower, a suitable method of production should be introduced. Besides, the essential oils of the *ferula* species have been indicated to have higher antimicrobial and antioxidant activity than plant extract; hence, an approach for high quantity yielding of essential oils is required. To cope with mentioned challenges and move toward industrial application, more research on the treatment of various food products with *ferula* species' essential oils and plant extract addition should be done.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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