The Apiaceae: Ethnomedicinal family as source for industrial uses

Bouchra Sayed-Ahmad[a,b], Thierry Talou[a], Zeinab Saad[b], Akram Hijazi[b], Othmane Merah[a,*]

[a] Laboratoire de Chimie Agro-industrielle (LCA), Université de Toulouse, INRA, INPT, Toulouse, France
[b] Doctoral School of Science and Technology, Research Platform for Environmental Science (PRASE), Lebanese University, Lebanon

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A B S T R A C T

Plants from Apiaceae family are commonly used for food, flavoring, fragrance and medical purposes; they are also known to be used as a household remedies since antiquity. Recently, many experimental and biological investigations have been carried out in order to validate the ethno-medicinal claims of plants belonging to this family. Moreover, rediscovery of this family can be responsible for launching a new generation of botanical chemicals for industrial applications. This review paper may help upcoming research activities on *Apiaceae family members* by giving up to date information on their main common features, their origins and traditional backgrounds. Furthermore, this review gathers and discusses the fragmented information described in literature concerning the chemical composition and the biological activities of essential oils and different extracts of some Apiaceae species, it illustrates also their potential for the development of pharmaceutical, cosmetic products and other industrial uses.

1. General introduction

Medicinal and aromatic plants have attracted the attention of re searchers worldwide as a major source of raw materials used in the pharmaceutical, cosmetic, flavor and perfumery industries. Despite the progress made in synthetic medication research, nowadays, the large numbers of drugs in use are derived from plants by applying modern technologies to traditional practices (Canter et al., 2005; Singh and Singh, 2001). Apiaceae family is one of the most important families of flowering plants, which consists of 3780 species in 434 genera. It is distributed throughout the world, mostly in the northern temperate regions and high altitudes in the tropics. The main common features of Apiaceae species are: aromatic herbaceous nature, alternate leaves with sheathing bases, hollow stems, small flowers, inflorescences determined in simple or compound umbel, and indehiscent fruits or seeds with oil ducts (Christensen and Brandt, 2006). This family is well known for its distinctive flavors due to the secretory cavities consisting of schizo genous oil ducts with resin, oil, or mucilage and located in the fruits, stems, leaves and roots (Berenbaum, 1990). Apiaceae family provides a large number of plants which are used for different purposes including nutrition, medicine, beverages, spices, repellents, staining, cosmetics, fragrances and industrial uses. Ethnomedically, several plants of this family are used as home based remedies to treat various illnesses re lated to digestive, endocrine, reproductive and respiratory systems (Aćimović and Kostadinović, 2015). This family is rich in phytochem icals and secondary metabolites which are potential source of drugs such as terpenoids, triterpenoid saponins, flavonoids, coumarins, polyacetylenes, and steroids. Furthermore, several species of this family are an excellent source of essential oils, more than 760 different com ponents from different chemical classes with high pharmaceutical in terest are detected in the essential oils within this family. Moreover, the seeds of Apiaceae species are identified as promising source of an unusual specific fatty acid; the petroselinic acid (C18:1n 12): its content in Apiaceae oilseeds is over than 50%; this fatty acid is the only isomer of oleic acid occurring naturally in plants; it has many potential uses as a valuable oleo chemical raw material for industry (Avato et al., 2001). In 2014, the European Commission authorised the placing on the market of coriander seed oil as a novel food ingredient under Regula tion (EC) No 258/97 of the European Parliament and of the Council since its richness petroselinic acid (Nguyen et al., 2015).

Several previous studies on Apiaceae family plant materials reveal their importance as potential source of natural agrochemicals as well as their biological activities such as anti tumor, antimicrobial, anti in flammatory, analgesic, radical scavenging, diuretic, gastrointestinal and anti obesity properties. Therefore, in view of this immense med icinal importance, it is important to compile a comprehensive review covering the phytochemical constituents of seeds from Apiaceae family, their various pharmacological activities concentrating on antioxidant, antibacterial and antifungal activities and their potential industrial applications.

* Corresponding author at: Laboratoire de Chimie Agro-Industrielle, 4 allée Emile Monso, 31030 TOULOUSE Cedex 4, France.
E-mail address: othmane.merah@ensiacet.fr (O. Merah).

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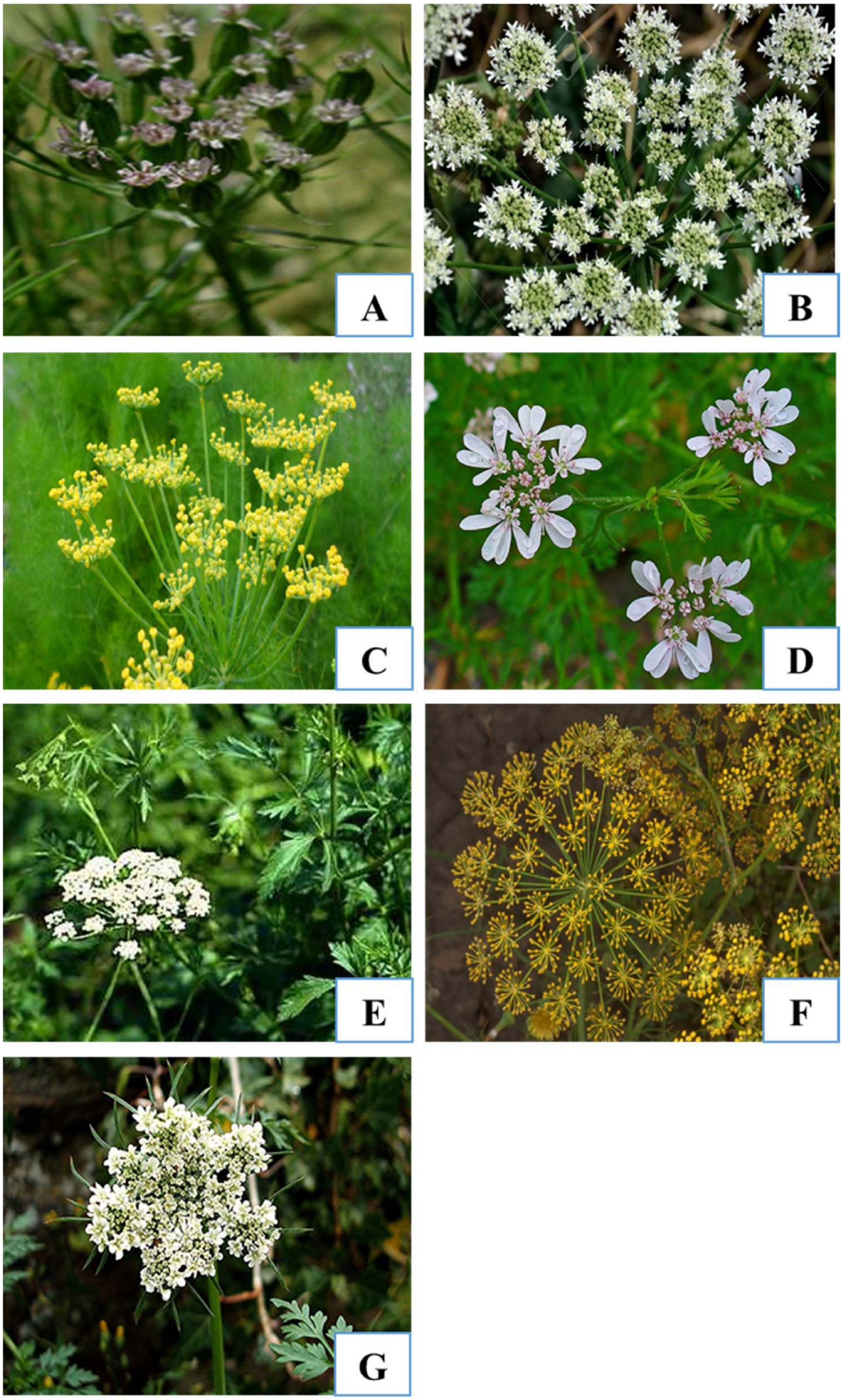

Fig. 1. **A**: cumin (*Cuminum cyminum* L.), **B**: caraway (*Carum carvi* L.), **C**: fennel (*Foeniculum vulgare* Mill.), **D**: coriander (*Coriandrum sativum* L.), **E**: anise (*Pimpinella anisum* Linn.), **F**: dill (*Anethum graveolens* L.) and **G**: parsley (*Petroselinum crispum* L.).

2. Origins and traditional uses

Apiaceae is one of the largest taxon among higher plants; cumin (*Cuminum cyminum* L.), caraway (*Carum carvi* L.), fennel (*Foeniculum vulgare* Mill.), coriander (*Coriandrum sativum* L.), anise (*Pimpinella anisum* L.), dill (*Anethum graveolens* L.) and parsley (*Petroselinum crispum* L.) (Fig. 1) are the most cultivated members of the family, grown on more than 1.2 million ha worldwide, their annual production is about 25 million tons.

Apiaceae family is considered as one of the oldest families among aromatic plants, most of its members are indigenous to Mediterranean region and Southwest Asia, they are introduced and cultivated

Table 1
Ethno-medicinal uses of Apiaceae species and chemical composition of their seeds essential oils.

Species	Common name	Origin	Ethno-medicinal use	Essential oil (%)	Main compound (%)	Other compounds	References
Cuminum cyminum L.	Cumin	Mediterranean region	Antispasmodic, carminative, astringent, treatment of diarrhea and digestive and respiratory disorders	2.5 – 4.5	Cuminaldehyde (27–50)	carotol, sabinene, β-terpineol, linalool, pinocarveol, γ-terpinene, myrtenal, copaene, α-pinene	Hajlaoui et al. (2010), Koppula and Choi (2011), Sowbhagya (2013)
Carum carvi L.	Caraway	Europe and West Asia	Galactologue, carminative, effective in polishing teeth & in the treatment of eczema, pneumonia and gastrointestinal disorders	0.5 – 1.4	Carvone (76.8–80.5)	Limonene, α-pinene, γ-terpinene, linalool, carvenone, *p*-cymene	R Fang et al. (2010), Laribi et al. (2009)
Foeniculum vulgare Mill.	Fennel	Mediterranean area	Gastrointestinal and neurological disorder, kidney stones, vomiting, diarrhea, antispasmodic, antiseptic, carminative and antiulcer properties	3–6	*trans*-anethole (69.7-78.3)	fenchone, estragole, d-limonene	Díaz-Maroto et al. (2006), Díaz-Maroto et al. (2005), Ghanem et al. (2012)
Coriandrum sativum L.	Coriander	Mediterranean region	Alleviate spasms, gastric complaints, bronchitis, gout, treat gastrointestinal disorders such as anorexia and diarrhea	0.03 – 2.6	Linalool (30–80)	γ-terpinene β-pinene, m-cymene, citronella, citronellol, citral, geraniol, citronellyl	Bhuiyan et al. (2009), Mahendra and Bisht (2011), Rajeshwari and Andallu (2011)
– *Pimpinella anisum* L.	Anise	Eastern Mediterranean region and Southwest Asia	Increase menstruation, urine, and sweat secretion, treatment of epilepsy, seizure, respiratory tract problems and bronchial asthmatic attacks	2–6	*trans*-anethole (77–94)	eugenol *trans*-anethole, methylchavicol, anisaldehyde, estragole, coumarins, scopoletin, umbelliferone, estrols	Gülçın et al. 2003, Orav et al. 2008, Pavlova et al. (2006)
Anethum graveolens L.	Dill	Mediterranean region and West Asia	Carminative, diuretic, galactogogue, stimulant, stomachic, treat gripe for babies and relieve hiccups and colic	1–4	Carvone (30–60)	limonene, α-phellandrene, pinene, diterpene, dihydrocarvone, cineole, myrcene, paramyrcene, dillapiole, isomyristicin, myristicin	Ishikawa et al. (2002), Rădulescu et al. (2010), Said-Al-Ahl et al. (2015)
Petroselinum crispum Mill.	Parsley	Mediterranean region	Treatment of hypertension, cardiac and urinary disease, diabetes, Alzheimer's disease, thrombosis and stroke	2–8	Myristicin (–)	α-pinene, β-pinene, ρ-cymene, limonene, apiol, elemicin	López et al. (1999), Soliman et al. (2015), Stankovic et al. 2004

worldwide due to their usage in foodstuff, pharmaceutical, perfume and cosmetic productions (Table 1) (Hunault et al., 1989; Jazani et al., 2008; Rajamanickam et al., 2013). Nowadays, India is the main worldwide suppliers of cumin seeds, with 80,000 170,000 tons of seeds grown in India, among them 10% are exported. Europe countries are the major producers of caraway seed such Sweden, Finland, Germany and Norway, as well as Morocco, Syria and India (Agrahari et al., 2014). On the other hand, India, Russia, Central Europe, Asia and Morocco are the principal countries for coriander commercial production (Asfaw and Abegaz, 1998) while, Turkey, Spain and China are the major producing countries of aniseed (Arslan et al., 2004).

Plants of the Apiaceae family demonstrate medicinal properties and have been used in traditional medicine since antiquity (Table 1), these crops are recommended for gastrointestinal and neurological disorder, vomiting and diarrhea, they show antispasmodic, antiseptic, carminative and antiulcer properties, especially cumin, caraway and fennel (Fang et al., 2010; Hajlaoui et al., 2010; Koppula and Choi, 2011). Moreover, caraway seeds are effective in polishing teeth and in the treatment of eczema and pneumonia (Ghanem et al., 2012) while seeds and different parts of coriander are used to alleviate spasms, gastric complaints, bronchitis and gout (Rajeshwari and Andallu, 2011). Ani seeds are found to increase menstruation, urine, and sweat secretion; they are useful also in the treatment of epilepsy, seizure, respiratory tract problems, and bronchial asthmatic attacks (Pavlova et al., 2006). Dill water have a soothing effect, it is used to treat gripe for babies, to relieve hiccups and colic (Said Al Ahl et al., 2015). *Parsley* is used in the treatment of hypertension, cardiac and urinary disease, diabetes as well as Alzheimer's disease, thrombosis and stroke (Soliman et al., 2015).

3. Essential oil and lipid composition

Apiaceae species are extensively used in everyday nutrition through drinks as beverages and through food in various formulations especially as spices (Tuncturk and Özgokce, 2015). Their seeds are sources of active compounds and considered as an excellent dietary supplement low in calorie and rich in fixed oil, proteins, fibers, carbohydrates and essential oil. However, a significant diversity of chemical composition is detected depending on the seed varieties, genetic sources and environmental conditions (Table 2). Apiaceae seeds are also a rich source of water soluble glycosides of monoterpenoid, alkyl and aromatic compounds as well as, cellulose, lignin, wax esters, pectins, phospholipids, flavonoids, hydroxycoumarins, carotenoids, terpenoids and other types of compounds including sugars, lactones and quinones (Jia et al., 2015).

Vegetable oilseeds from Apiaceae members are generally obtained through Soxhlet and cold pressing extraction. These oils are known to performed a wide range of industrial applications including lubricants, detergents, printing inks, soaps, shampoos, plasticizers and disinfectants (Sharma et al., 2005). In Apiaceae family, vegetable oils consist primarily of petroselinic acid followed by linoleic acid; other fatty acids such as palmitic, myristic, capric and *cis* vaccenic acids are also identified in their vegetable oils but at lower concentrations. (Shahnaz et al., 2004). Actually, petroselinic acid has many potential uses: its cleavage products adipic and lauric acids. Obtained by ozonolysis, these products can be used for several technical purposes: adipic acid is used for the production of softeners and nylon, while lauric acid is used as a raw material for the production of softeners, emulsifiers, detergents and soaps (Reiter et al., 1998). Moreover, the addition of oils rich in petroselinic acid to food products gives rise to a number of advantages by improving their textural properties without increasing the level of LDL cholesterol in the blood serum. In addition to its anti inflammatory potential, petroselinic acid can be used also in cosmetic formulations involved in hair treatment and skin care as a moisturizing agent.

On the other hand, Apiaceae oilseeds are considered as a good source of phytosterols, β sitosterol and stigmasterol are generally the main constituents while Δ^5 avenasterol, lanosterol, brassicasterol and

Table 2
Nutritional compositions and chemical composition of fixed oils of Apiaceae seeds.

Species	Moisture	Ash	Protein	Carbohydrates	Fiber	Soluble sugars	Fixed oil (%)	Petroselinic acid (%)	Sterol (%)	Main Tocopherol	References
Cuminum cyminum L.	8.1	9.3	17.8	44.2	10.5	2.3	10 – 2	41–55.9	0.3	β-tocopherol	Bettaieb et al. (2011), Dua (2012), Nadeem and Riaz (2012), Ramadan et al. (2012)
Carum carvi L.	4.2	4.1	7.6	50.1	25.3	0.6	6.2–10.1	29.4–40.6	0.2 – 0.7	α-tocopherol	Khalid et al. (2005), Laribi et al. (2013), Reiter et al. (1998), Thippeswamy and Achur (2014), Zlatanov and Ivanov (1995)
Foeniculum vulgare Mill.	6.3	13.4	9.5	42.3	18.5	1.1	10–14.4	70–80	0.6	γ-tocotrienol	Anubhuti et al. (2011), Barros et al. (2010), Coşge et al. (2008), Matthäus and Musazcan Özcan, (2015), Nassar et al. (2010)
Coriandrum sativum L.	11.3	5.0	11.4	54.9	28.4	1.9	9.9–27.7	65.7–76.6	3.6 – 5.1	γ-tocopherol	(Ganesan et al., 2013, Horvath et al., 2006, Ramadan et al., 2012, Sahib et al., 2012)
Pimpinella anisum Linn.	13	10	18	55	25	5	8–11	56	0.2 – 0.7	α-tocopherol	Besharati-Seidani et al. (2005)
Anethum graveolens L.	8.3	9.8	15.6	36	4.8	–	15.3–18.2	18.7	0.24	α-tocotrienol	Isopencu and Ferdeş (2012), Matthaus et al. (2003), Piironen et al. (2003)
Petroselinum crispum Mill.	4.8	8.0	25	30.6	11.0	5	9.4–11.3	62.8–71.6	0.2	–	(Ellenbracht et al., 1980, Khalil et al., 2012, Shams et al., 2015)

campesterol are recognized as minor compounds (Table 2). In fact, the market of phytosterols is expected to grow considerably for the next five years in almost all parts of the world, especially in European and North American countries. The valuable role of phytosterols in health, pharmaceutical and food and feed areas is being well recognized, namely in pharmaceuticals (production of therapeutic steroids), nu traceutical (anti cholesterol additives in functional foods, anti cancer properties) and cosmetics (creams, lipstick) (Fernandes and Cabral, 2007).

Essential oil can be extracted from all parts of Apiaceae plants (Barros et al., 2010), however, the highest amount is found in their seeds where it is located in the glands in the mericarp (Kim et al., 2011; Neffati and Marzouk, 2008). This oil is responsible of the characteristic odor of seeds due to its chemical composition, principally to the present aldehydes. Essential oils are widely used in food flavoring, industry perfumery, coloring, soap, detergents (Salehi Sardoei et al., 2014). As for fennel seeds, essential oil is responsible of the anise odor which makes it a flavoring agent in food and beverage products, as well as for coriander seeds where the aroma and flavor are attributable to this oil which is one of the 20 major essential oils in the world market. Gen erally, oils obtained from Apiaceae seeds are yellowish to colorless with a fresh flavored odor. Different methods are used for oilseed extraction including hydrodistillation, steam distillation, extraction with classical solvents, supercritical fluid extraction (SFE), headspace solvent micro extraction and solid phase microextraction (SPME) (Li et al., 2009). However, seed origins, maturity stages, environmental factors as well as extraction and analytical methods affect significantly the yield and the chemical composition of oils (Zheljazkov and Shiwakoti, 2015) (Table 1).

4. Phenolics, flavonoids and antioxidant properties

Polyphenolic compounds such as flavonoids, tannins, and phenolic acids are commonly found in Apiaceae extracts. Topical applications of cosmetic formulations containing phenolic compounds can reduce the causes and effects of skin aging, skin diseases and damage such as wounds and burns (Działo et al., 2016). The effective role of phenols including flavonoids based spray as anesthetic and analgesic combi nations in painful areas have been confirmed previously (Farrer, 2012). Also, a combination of 5% phenol in glycerin is one of the most effec tive and safest procedures in the management of serve pain caused by rectal and genital cancer (Comelli et al., 1980). Phenolic compounds are found to inhibit either the production or the action of pro in flammatory mediators, resulting in anti inflammatory capacity, thus they can be considered as an effective alternative of anti inflammatory drugs which are usually used with the subsequent occurrence of adverse side effects (Ambriz Perez et al., 2016). Moreover, phenolics are used in a wide range of other industrial applications, including many types of high performance coatings, rubbers and dyes.

In the case of cumin seeds the Total phenolic contents (TPC) varies from 9 to 35.3 mg of Gallic acid equivalents per gram of dry weight (mg GAE/g DW) depending on solvent used in extraction and seed varieties. A high and variable TPC is also exhibited by cumin organs; flower ex tract has the highest TPC followed by stems and leaves, and roots (19.2, 15.6, 11.8 mg GAE/g DW, respectively); as for polyphenols, Total Flavonoid Contents (TFC) varies from 0.4 mg of catechin equivalent per gram of dry weight (mg of CE/g of DW) to 5.6 mg CE/g DW in all cumin plant parts (Bettaieb et al., 2010; Gupta, 2013). Furthermore, TPC of cold pressed caraway seed oils is about 3.5 mg GAE/g, this content reaches 6.0 mg GAE/g and 5.9 mg caffeic acid/g DW (CAE/g DW) in the methanolic extracts of seeds and 1.84 mg GAE/g in the areal parts; in contrast, TFC ranges from 2.5 to 12.8 mg rutin (RE/g DW) in caraway seeds methanolic extracts, while areal parts contain only 3.6 mg RE/g DW (Amri et al., 2015; Pirbalouti et al., 2013). Several flavonoids compounds are identified from different caraways parts: polyacetylenic compounds are detected in the seed and roots, isoquercitrin and astragalin are found in the leaves and flowers (Najda et al., 2008; Saghir et al., 2012).

Fennel extracts are considered as a rich source of phenolic com pounds such as flavonoids, phenolic acids, coumarin and tannins; ros marinic acid and chlorogenic acid are the major phenolics found in the methanolic extracts of their seeds while quercetin and apigenin are the major flavonoids. Phenolic and flavonoid contents in the methanolic extract of dry seeds of fennel are 1017.3 mg GAE/100 g DW and 695.5 mg QE/100 g DW, respectively. Methanolic extracts of fennel parts are also investigated for their phenolic and flavonoid contents, results show a high phenolic content in stems, shoots, leaves and in florescences, but flavonoids are detected only in the shoots (Nagy et al., 2014; Rahimi and Ardekani, 2013; Roby et al., 2013).

The polyphenolic contents of coriander seed extracts range from 12.1 to 15.2 mg GAE/g in the methanolic extracts, and from 70.2 to 66.6 mg/g in the ethanolic extracts. On the other hand, TPC of me thanolic and aqueous extracts of coriander is also assessed: results show that they contain 110 and 63.2 mg/100 g of TPC in their leaves, re spectively, and 89.3 and 51.6 mg/100 g TPC in their stems, respec tively. The TFC of methanolic seed extracts vary from 11.1 to 13.2 mg CE/g DW where quercetin, keampferol, rhamnetin and apigenin are the main detected flavonoids (Christova bagdassarian et al., 2014; Joglekar et al., 2012; Rahiman et al., 2012; Sriti et al., 2011).

Regarding aniseed extracts, several phenolic components are iden tified including guajacol, anisol, vanillin and anisalcohol. TPC of ani seed oil ranges from 18.7 to 26.8 mg GAE/g while TPC and TFC of aniseed methanolic extracts vary between 46.2 mg GAE/100 g and 17.4 mg CE/100 g, the main flavonoid identified are areluteolin, rutin, isoorientin, isovitexin and quecertin 3 *O* glucuronide (Christova Bagdassarian et al., 2013).

Dill ethanolic and aqueous extracts show the highest TPC (71.3 and 65.1 mg GAE/g of the dried plant, respectively) followed by acetone extract (55.5 mg GAE/g). Likewise, TPC and TFC of ethanolic extracts (70% v/v) are 105.2 mg GAE/g and 58.2 mg CE/g of the dried extract, respectively; two flavonoids are isolated from dill seed: quercetin and isoharmentin (Bahramikia et al., 2008; Möhle et al., 1985). The phy tochemical screening of the crude powder of different parts of dill shows that leaves, stems and roots are rich in tannins, terpenoids and cardiac glycosides. Tannins can be used as renewable components for industrial adhesives applications which can alleviate dependence on petroleum derived products. Tannin lignin fractions can be used also as substrates for biopolymers and composites for manufacturing of auto motive interior design, furniture, construction industry and musical instruments (Wheatley, 1992). On the other hand, plant terpenoids can be used as industrially relevant chemicals, including many pharma ceuticals, flavors, fragrances, pesticides and disinfectants, and as large volume feedstocks for chemical industries. Several terpenoids possess pharmaceutical properties and are widely used in clinical practice. Among them taxol, a diterpene from yew, which has effectively been recognized as a major antineoplastic agent, and artemisinin, a sesqui terpene lactone, which is an effective antimalarial agent (Caputi and Aprea, 2011).

TPC values of leaves and stems extracts of parsley range from 9.6 to 42.3 mg GAE/g, the dichloromethane extract showed the highest TPC among the extracts. In another study, ethanolic leaves extracts show higher polyphenolic and flavonoid contents (54.2 and 42.1 mg/g, re spectively) than methanolic and chloroform extracts. The two major phenolic compounds extracted from parsley are apiin and malonyl apiin; flavonoids are the major compounds in this plant; apigenin, cosmosiin, oxypeucedanin hydrate are detected in the aqueous extracts of the leaves; the main flavonol constituents found are kaempferol and quercetin (Farzaei et al., 2013; Tang et al., 2015; Trifunschi and Ardelean, 2012).

Oil, aqueous, methanolic, ethanolic and acetone extracts of different parts of Apiaceae are investigated for their antioxidant activity using several methods including free radical scavenging, superoxide anion

Table 3
Main antioxidant activities exhibited by some Apiaceae seed extracts.

	Antioxidant assay	Extract type	Extract concentration	Inhibition Percentage	Ref.
C. cyminum L.	DPPH radicals, FRAP, reducing Fe^{2+} ions	Methanolic extract	240 μg/ml	56.8% of DPPH radicals	Rahman et al. (2015)
C. carvi L.	DPPH radicals, lipid peroxides, ORAC	Aqueous extract	105 μg	50% of superoxide radicals	Satyanarayana et al. (2004)
F. vulgare Mill.	Peroxidation of linoleic acid	Ethanolic extract	100 mg	99.1% of peroxidation of linoleic acid system	Oktay et al. (2003)
C. sativum L.	DPPH radicals, FRAP	Methanolic extract	500 μg/ml	64.4% of DPPH radicals	Wangensteen et al. (2004)
P. anisum L.	DPPH radicals and superoxide anion scavenging, hydrogen peroxide scavenging, metal chelating activities	Ethanolic extract	2.1 mg/ml	50% of DPPH radicals	Rajeshwari et al. (2011)
A. graveolens L.	DPPH radical scavenging, Trolox equivalent antioxidant capacity (TEAC), reducing power	Aqueous extract	400 μg/ml	89.7% of DPPH radicals	Ramadan et al. (2013)
P. crispum L.	DPPH radical-scavenging, reducing power of ferric-ferricyanide complex	Methanolic extract	2 mg/ml	19.3% of DPPH radicals	Farzaei et al. (2013)

radical scavenging, hydrogen peroxide scavenging and metal chelating activity (Table 3). Antioxidants have many industrial uses, such as preservatives in food products, but also they can be added to fuels and lubricants in order to prevent their oxidation, and in gasoline to inhibit their polymerization. Antioxidants can be also added to polymers including rubbers, plastics and adhesives to stop their oxidative damage and loss of strength and flexibility (Robert and Dunn, 2005).

Cumin essential oil exhibits a higher 1,1 diphenyl 2 picrylhydrazyl (DPPH) radical scavenging activity than that of butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), the inhibition percentage reaches 85.4% at a concentration of 240 μg/ml, and this might be due to the presence of appreciable amounts of antioxidant compounds such as cuminal, γ terpinene, pinocarveol, carotol, pinocarveol and linalool. A comparative results of antioxidant activity are obtained using ferric reducing ability of plasma (FRAP) and reducing Fe^{2+} ions assays. Methanol, ethanol, dichloromethane, chloroform, hexane and aqueous cumin seed extracts are found to have antioxidant properties. A dose dependent DPPH radical scavenging activity is exhibited by the nonvolatile extracts, the methanolic extract shows the highest inhibition percentage (Table 3); on the other hand, a highest superoxide radical scavenging activity was found in ethyl acetate extract (IC_{50} = 18.3 μg/ml). The evaluation of antioxidant activities of acetone extracts of different cumin parts shows that the flower extract has the strongest lipid peroxidation inhibition, reducing agent and DPPH radical scavenging activities while the stem and leaves extracts show the highest chelating power (El Ghorab et al., 2010; Rahman et al., 2015).

Oils, aqueous and solvent derived extracts of caraway seeds possess an excellent antioxidant effects (Table 3). Antioxidant activity of essential oil extracted from caraway seed is significantly higher than several standard antioxidant compounds; this high activity is attributed to the presence of active antioxidant compounds such as carvone, linalool, estragol and other phenolic compounds (Agrahari et al., 2014). Aqueous extract of caraway seeds has a high antioxidant activity, 105 μg of extracts can inhibit 50% of superoxide radicals. Aqueous extracts of caraway roots show also an important DPPH radical activity which is referred to their richness in various types of secondary metabolites. (Saleh et al., 2010; Satyanarayana et al., 2004)

Essential oil of fennel seeds shows a stronger antioxidant activity in comparison with aqueous and ethanolic extracts. Such a great antioxidant activity is due to the high content in polyphenols and flavonoids such as 3 caffeoylquinic acid, 4 caffeoylquinic acid, 1,5 *O* dicaffeoylquinic acid, rosmarinic acid, eriodictyol 7 rutinoside, quercetin 3 *O* galactoside, kaempferol 3 *O* rutinoside and kaempferol 3 *O* glucoside (Oktay et al., 2003; Ruberto et al., 2000; Shahat et al., 2011).

Seeds, leaves and stems extracts of coriander are investigated for their antioxidant activity using different bioassays such as DPPH free radical scavenging activity assay and ferric reducing antioxidant power (FRAP). Results show that ethanolic, methanolic and aqueous extracts of leaves exhibit a higher antioxidant activity as compared with seeds extracts; the radical scavenging activity of methanol extracts of both seed and leaves, at 500 μg/ml, are 64.4% and 72.2%, respectively, this strong activity can be referred to the high carotenoid content in coriander leaves. Yet, coriander seed essential oil shows a greater radical scavenging activity than leaves essential oil which is attributed to the higher linalool content in oilseed (El Ghorab et al., 2010; Nguyen et al., 2015; Shahwar et al., 2012; Wangensteen et al., 2004). Actually, linalool and limonene are among the most common fragrances used in cosmetics preparation. They can be found in many sort of cosmetic products such as shampoos, hair conditioner, shower gels, rinse off creams and lotions products (Siti Zulaikha et al., 2015).

Aqueous and ethanolic extracts of aniseeds show a higher antioxidant activity than standard antioxidants such as BHA, BHT and α tocopherol using different antioxidant tests (DPPH radicals and superoxide anion scavenging, hydrogen peroxide scavenging, and metal chelating activities) (Table 3). Aniseed fruit extracts exhibit the strongest antioxidant activity among six other Umbelliferae fruits using DPPH radical scavenging activity test (Nickavar et al., 2009; Rajeshwari et al., 2011).

Antioxidant activity of dill extracts is evaluated with DPPH radical scavenging, Trolox equivalent antioxidant capacity (TEAC), reducing power, chelating power, and β carotene bleaching assays (Table 3). In all assays, ethanolic extract of dill flower shows higher activity than that of seed and leaves extracts. This is may be due to the presence of phenolic compound including flavonoids and proanthocyanidins in flower extracts. Furthermore, an excellent, dose dependent antioxidant activity have been reported for dill aqueous extract, percentages of inhibition are 87.5 and 89.7% at 400 µg/ml according to the β carotene linoleate and DPPH free radicals methods, respectively (Ramadan et al., 2013; Shyu et al., 2009).

Parsley extracts exhibit a strong antioxidant activity, essential oils show an EC_{50} values of 5.1 and 80.2 mg/ml in the β carotene bleaching and the DPPH radical scavenging assays, respectively. This activity is attributed to the presence of apiol and myristicin in the oil. Methanolic extracts of stems and leaves show antioxidant properties by DPPH radical scavenging, reducing power of ferric ferricyanide complex, ferrous ion chelating, iron induced linoleic acid oxidation mode and hydroxyl radical scavenging assays. On the other hand, in a clinical trial, the addition of parsley leaves in the diet of 14 person results by a significant increasing of antioxidant enzymes; apigenin is reported to be the active constituent responsible for its activity (Farzaei et al., 2013; Tang et al., 2015).

5. Antibacterial and antifungal properties

Several studies show the effectiveness of cumin essential oil against different Gram positive and Gram negative bacterial species (Table 4). Minimum inhibitory concentrations (MIC) values of cumin essential oil against *M. tuberculosis* ranges from 6.3 to 25 µg/ml; this activity can be referred to the presence of cumin aldehyde in volatile oils (Derakhshan et al., 2008). This oil shows also a significant antifungal activity against *P. boydii* and *A. flavus* (88.2 and 66.7%, respectively) (Rahman and Choudhary, 2000). Ethanolic extract of cumin seeds exhibit also antibacterial activity against *Helicobacter pylori* (MIC_{90} values of 0.075 mg/ml) (Nostro et al., 2005).

Caraway seed essential oils show antibacterial activities against numerous Gram positive and Gram negative bacteria strains. MIC values of caraway oils against *E. coli* and *S. aureus* are 0.6 and 0.5%, respectively, while the minimum bactericidal concentration (MBC) values are 0.8 and 0.6%, respectively. These results suggest the possible use of caraway seed oil as an antibacterial agent against human pathogens and for the control of bacterial infections (Iacobellis et al., 2004; Mohsenzadeh, 2007). Several investigations show that carvone, limonene and linalool are responsible of the antibacterial effects of caraway seed oils. Likewise, ethanolic extracts of caraway seeds inhibit the growth of *Lactobacillus* species (Damasius et al., 2007). Caraway oils exhibit high inhibitory effects against various fungal species including the mycotoxigenic *Aspergillus* species. They are considered as a potential candidates in controlling aflatoxins of food and feeds (Razzaghi Abyaneh et al., 2009; Skrinjar et al., 2009).

Numerous studies indicating the antibacterial activity of *fennel are reported in the literature (*Table 4). Fennel stem extract shows a high inhibition against B. subtilis, A. niger and C. cladosporioides with MIC values 25, 250 and 125 µg/ml*, respectively.* The aqueous extract of aerial part of *fennel can* inhibited the growth of *A. radiobacter pv. tumefaciens*, *E. carotovora*, *P. fluorescens*, and *P. glycinea.* Fennel essential oil exhibits a higher antibacterial activity in comparison with methanolic and ethanolic extract. MIC and MBC of fennel oil values are 1 and 2% against *E. coli*, 2 and 4% against *S. aureus*, respectively. This oil shows a low activity against *B. cereus* and *P. aeruginosa* (Aprotosoaie et al., 2008; Duško et al., 2006; Gulfraz et al., 2002; Kwon et al., 2002). Essential oil of fennel exhibits also antifungal activity against several

Table 4
Main antimicrobial activities exhibited by seeds from Apiaceae family.

Seeds	Bacterial strain	MIC values	Fungal strain	MFC values	Ref.
C. cyminum L.	*S. epidermidis, S. aureus, B. subtilis, S. epidermidis, M. luteus, B. cereus, E. coli, L. monocytogenes, E. feacalis, P. aeruginosa, S. typhimirium, M. tuberculosis*	6.3 to 25 µg/ml	*P. boydii, A. flavus*	0.075 mg/ml	Rahman and Choudhary (2000),Derakhshan et al. (2008), Johri (2011)
C. carvi L.	*S. aureus, B. cereus, E. coli, S. enteritidis, X. brasilicum*	0.5 − 0.6%	*Aspergillus* species	1 µl/ml	Iacobellis et al. (2004), Mohsenzadeh (2007), Razzaghi-Abyaneh et al. (2009), Skrinjar et al. (2009)
F. vulgare Mill.	*B. cereus, B. megaterium, B. pumilus, B. subtilis, E. coli, K. pneumonia, M. luteus, P. putida, P. syringae, C. albicans.*	2–4%	*C. cladosporioides, P. helianthi, T. mentagrophytes, A. niger, A. flavus, F. graminearum F. moniliforme*	6 µl	Badgujar et al. (2014), Clara Aprotosoaie et al. (2010), Gulfraz et al. (2002), Kwon et al. (2002), Taie et al. (2013)
C. sativum L.	*Salmonella, Citrobacter freundii, Enterobacter aerogenes, E. coli, K. pneumoniae*	4.2 µl/ml	*C. palliscen, F. oxysporum, F. moniliforme, A. terreus*	31.2–62.5 µg/ml.	Begnami et al. (2010), Bhat et al. (2014), Saeed and Tariq (2007)
P. anisum L.	*C. albicans, C. parapsilosis, C. tropicalis, C. krusei, C. pseudotropicalis*	6.3-12.5 mg/ml	*A. alternata, A. niger, A. parasiticus*	17-20%	Akhtar et al. (2008), Al-Bayati, (2008), Yazdani et al. (2009)
A. graveolens L.	*S. aureus, Bacillus cereus, E. faecalis, L. monocytogenes, E. coli, Y. enterocolitica, S. choleraesuis*	20–80 mg/ml	*C. albicans, P. islandicum, A. flavus*	1.56–100 mg/ml	Delaquis et al. (2002), Rifat-uz-zaman et al. (2006), Singleton et al. (1999), Stavri and Gibbons (2005)
P. crispum L.	*S. aureus, V. cholera, Y. enterocolitica, S. enterica, E. coli*	4–30%	*A. parasiticus*	4 ml/ml	Fatemeh et al. (2010), Shariatifar et al. (2014)

strains, it shows complete zone of inhibition at 6 µl dose. Aqueous seed extracts have significant antifungal activity against fungi by compar ison with grisofulvin: a reference fungicidal agent (Badgujar et al., 2014; Mimica Dukić et al., 2003; Singh et al., 2006; Taie et al., 2013).

Coriander leaves essential oil is reported to have an inhibitory effect against several Gram positive and Gram negative bacterial strains. Seed essential oil is also found to inhibit 25 bacterial strains (MIC is about 4.2 µl/ml to most bacterial strains); antibacterial activity of coriander essential oil is attributed to its high linalool content (Table 4). The minimum fungicidal concentrations (MFCs) of coriander seed essential oil against *Candida spp*. range from 31.2 to 62.5 µg/ml (Begnami et al., 2010; Bhat et al., 2014; Saeed and Tariq, 2007).

Essential oil and methanolic extracts of aniseeds show a strong antibacterial activity against *Staphylococcus aureus*, *Bacillus cereus*, and *Proteus vulgaris*. Aqueous and methanolic extracts 50% (v/v) are tested against 4 pathogenic bacteria (*Staphylococcus aureus, Streptococcus pyogenes, Escherchia coli, and Klebsiella pneumoniae*). Results show that they exhibit a good antibacterial activity against all of the tested bac teria, the aqueous extract shows the highest effectiveness. Likewise, a strong antimycotic activity is exhibited by the fluid extracts of aniseed (MIC between 17 and 20%) against several *Candida* strains; the largest inhibition zone is detected in *C. albicans* (Akhtar et al., 2008; Al Bayati, 2008; Yazdani et al., 2009).

Antibacterial activity of dill seed extracts is assessed using agar diffusion assay, MIC and viable cell count studies (Table 4). Essential oil and acetone seed extracts exhibit a good antibacterial activity against four Gram positive bacteria and four Gram negative bacteria, this ac tivity can be attributed to the presence of furanocoumarin (Delaquis et al., 2002; Rifat uz zaman et al., 2006; Stavri and Gibbons, 2005).

Hot and cold water extracts from parsley leaves possess anti bacterial activity against *P. aeruginosa, S. aureus* and *S. pyogenes* isolated from patient with burn infection. MICs of parsley seeds and leaves es sential oils are 8 and 0.25% against *S. aureus*, 4 and 0.12% against *V. cholera*, 16 and 0.5% against *Y. enterocolitica* and 32 and 1% against the *S. enterica* and *E. coli*, respectively. Methanol extracts of parsley leaves demonstrate antimicrobial activity on *B. subtilis, P. aeruginosa, S. epi dermidis, S. aureus* and *S. cerevisiae in vitro*; coumarins are reported to be responsible components for this property. Parsley extracts possess also a great antifungal activity, MIC of essential oil is 4 µl/ml against *A. parasiticus* (Fatemeh et al., 2010; Shariatifar et al., 2014). However, recent studies highlighted the fungicidal and insecticidal effects of es sential oils of several Apiaceae species (Benelli et al., 2013; Meepagala et al., 2005).

6. Industrial applications

Various products and byproducts derived from Apiaceae family can be considered as easily accessible, cheap and e*nvironmentally friendly* raw materials for several industrial and commercial preparations ran ging from their uses in the cosmetic and pharmaceutical industries, to their uses as food additives and other industrial applications. It has been reported that enrichment of food formulations with flours from Apiaceae seeds can improve their nutritional values, physical and chemical properties as well as their biological activities. Essential oil from caraway seeds (0.05 0.15%) can be used as natural preservative in foodstuffs by inhibiting the rate of oxidation products formation and the growth of fungi during 60 days storage of cake (Darougheh et al., 2014). Also, adding 5% of cumin powders to cookies flour can enhance their texture, taste and their overall acceptability, it improves their antioxidant properties and increase the TPC value 40% than the control (Abdel Shafi Abdel Samie et al., 2010). Bread is one of the basic foods in many countries, studies show that white bread formulated with 5 7% of fennel seed powder can make it healthier by increasing TPC value, antioxidant activity and consumer acceptability (Das et al., 2013). Moreover, 0.05% of fennel essence can be used as natural preservative of baguette bread instead of dangerous chemical preservative while maintaining the same texture, color and sensory properties of the bread (Salehi et al., 2015). Coriander leaves powders can be also supple mented to wheat bread, the optimum concentration that offered the better acceptability is between 5 and 7% (Das et al., 2012). Essential oil from coriander seeds can be used to increase antioxidant and antifungal activities as well as organoleptic properties of foodstuffs rich in lipids (Darughe et al., 2012). Pies enriched with aniseeds show superior sensory quality associated with improvement of protein, minerals, fiber and fat content and better antioxidant and antimicrobial properties (Hussein et al., 2014). Likewise, incorporation of dehydrated dill leaves in Indian paratha enhances fiber, chlorophyll and carotenoid content and the overall quality characteristics (Sudha et al., 2015). Similar re sults are obtained in the case of fortified pasta with parsley leaves, the final product showed higher phenolic and antioxidant potential (Sęczyk et al., 2015).

Apiaceae family members can be identified as industrial crops for essential oils production and as potent renewable sources for com mercially important fine chemicals isolation including aldehydes, aro matic compounds, saturated and unsaturated hydrocarbons, mono terpenes and sesquiterpenes. Hydrocarbons and aldehydes comprise the main groups of these chemicals in Apiaceae seed oils. Currently, volatile hydrocarbons are used as propellants in aerosol sprays, due to chloro fluorocarbon's impact on the ozone layer. While the unsaturated hy drocarbons are used for sustainable chemistry applications for the production of diverse products including solvents, plasticizers, lu bricants and industrial raw materials. On the other hand, aldehydes are recommended for commercial applications either as precursors for the production of oxo alcohols (used in detergents), or as ingredients for perfumes and flavors industries (Evergetis and Haroutounian, 2014).

Oils and extracts of Apiaceae seeds are widely used in pharmaceu ticals as flavoring agent in mouth wash and as fragrance component in toothpastes, soaps, lotions and perfumes and candies. In fact, most of perfumery industries and aromatherapies are highly dependent on the supply of oils from anethum seeds (Jana and Shekhawat, 2010). Cor iander oils are also used in cosmetic emulsions, their addition showed helpful effects in cellulites, relieving of facial neuralgia and in fighting of fungal effects. They are useful in arthritis, broken capillaries, dan druff, eczema, muscular aches and pains, rheumatism, spasms, stiffness and sweaty feet (Athar and Nasir, 2005). Enrichment of water in oil emulsions based cream with ethanolic extract of fennel *seeds* resulted in improvement of moisture content on human skin as it reduced *trans* epithelial water. Skin mechanical properties were also improved, that is, diminish levels of roughness, and wrinkles of photo aged skin (Jadoon et al., 2015). Moreover, it has been demonstrated that essential oils and phytochemicals isolated from Apiaceae family are a potential alternative of conventional synthetic insecticides. They can be used in different ways to control a wild varieties of pests owing to their neu rotoxic activity including hyperactivity, seizures, and tremors followed by paralysis (Ebadollahi, 2013).

Recently, the potential uses of residual cakes from coriander seeds extrusion through single screw have been investigated for agro mate rials production. A thermo pressing technique was performed for fi berboards manufacturing from these cakes. Thus, renewable and bio degradable fiberboards with good mechanical and thickness swelling properties that can be used as boards for interior layouts, including furniture (based on the French standard NF EN 312) were obtained (Uitterhaegen et al., 2016).

7. Conclusion

This review summarizes the current statues of research studies re lated to the phytochemical analysis of some plants belonging to the Apiaceae family. It suggests that Apiaceae member's extracts represent a good source of natural bioactive compounds which could be valuable for pharmaceutical, food and cosmetic uses. Moreover, chemical con stituents as well as antioxidant and antimicrobial efficacy shown by essential oils and crude extracts from these plants provide an experimental and scientific proofs for their various traditional uses as homemade remedies and justify their further exploration for the development of novel effective eco friendly industrial applications. Nevertheless, the utilization of extrusion technique appears as a new approach for extraction of eco friendly chemicals from Apiaceae species. It is a good alternative for sequential extraction of several compounds (vegetable and essential oils), but also for valorization of residual meals for agromaterial and foodstuff production.

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