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Chapter 9

Coriander and Its Phytoconstituents for the Beneficial Effects

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Additional information is available at the end of the chapter

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Abstract

Coriander (*Coriandrum sativum* L.) is a very popular medicinal plant that belongs to Apiaceae family in taxonomic classification, which is widely used as a spice and also in pharmacy and in food industries. The plant used in folk medicine, especially in Egypt, it has been known as one of the earliest spices. Coriander (Cilantro, Kişniş, Chinese parsley, *Coriandrum sativum*) is extensively recognized in almost every recipe. The genus Coriander was represented in *Flora of Turkey* by two different species called *C. sativum* L. and *C. tordylium* (Fenzl) Bornm. It is mainly cultivated for the seeds (fruits) that contain essential oil, fatty acids, coumarins, flavonoids, and polyphenols. Nowadays, the fruits exhibit internally carminative, spasmolytic, and galactagogic effects in many disorders. The use of coriander in different forms includes a wide range of fresh and dried herbs. The current section focuses on coriander oil in different forms, including the plant, its terpenoid profile, and all the miracle effects of coriander together with future prospects.

Keywords: Apiaceae, coriander, *Coriandrum sativum*, Kişniş, oil

1. Introduction

Medicinal and aromatic plants have been very popular in all the time for the culinary, medicinal, and many other purposes. The plants and their secondary metabolites (phytochemicals) take part in increasingly in foods, in health, and in nutritive products. The essential oils are the most popular secondary metabolites of the plants, used for thousands of years (over 5000 years) regarding the variety of objectives, principally for their health benefits [1]. In the history, the term essential oil dated back to the sixteenth century and comes from the drug Quinta essentia, named by Swiss physician Paracelsus von Hohenheim of Switzerland.

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Essential oil or essence is referred to by this name due to their flammable principle. In many kinds of the literature, the essential oils have been defined [2]. Briefly, essential oils are secondary metabolites biosynthesized in different plant organs [3] obtained by mainly hydrodistillation from almost all parts of the aromatic plants growing temperate regions in the world, of the secretory special elements with volatile properties along with characteristic fragrances, as limpid and rarely colored, soluble, in organic solvents [4]. The chemical composition of the essential oils is quite complex including mostly terpenes (monoterpenes and partly sesquiterpenes formed by isoprene) and aromatic compounds derived from phenylpropane and phenolic constituents [3, 5]. The essential oils known as fragrant oils, steam volatile liquids, or semiliquids, ethereal oils are concentrated hydrophobic aromatic oil. The flavor (fragrance and flavor) of the essential oils is marvelous due to reflecting their corresponding sources as mean basically plant [3]. The physiological effects of the essential oils are not clear but can say that protect the plants against microorganisms, insects, or attract them for the pollination [5]. The conventional methods to obtain the essential oils are hydrodistillation, steam distillation, solvent extraction, Soxhlet extraction, cold pressing method, enfleurage, cohobation, and maceration. By the way, distillation is absolutely the most common method of obtaining essential oils. In addition, innovative techniques can be covered supercritical fluid extraction (SFE), microwave-assisted hydrodistillation (MAHD), ultrasound-assisted extraction (UAE), solvent-free microwave extraction (SFME) and microwave hydro diffusion and gravity (MHG) [3]. Analytical monographs have been published by European Pharmacopeia (EP), International Organization of Standardization (ISO), World Health Organization (WHO), Council of Europe (COE) to ensure good quality of essential oils. The essential oils are exhibited in many important biological activities [1–5] and discussed in many kinds of the literature but mainly antibacterial and antifungal activities are dominated [6]. Essential oils are also commercially important, especially in the pharmaceutical, agronomic, food, sanitary, and cosmetic and perfume industries. Moreover, essential oils are the main therapeutic agent in aromatherapy as it forms mixtures with vegetal oil in several forms [3, 7, 8]. Essential oils are classified as "Generally Recognized as Safe" (GRAS) by the Food and Drugs Administration (FDA); therefore, they are not counted as harmful and, due to their natural origin, are more widely endorsed by consumers than "synthetic" agents [6], if it is used reasonably and carefully. In fact, there are so many things to say regarding essential oils, but this section will be interested in coriander as aromatic plant and its essential oil. Hence, in this chapter, we discuss the essential oil of coriander, which is very important in many fields called as food, spice, cosmetic, and of course pharmaceutical. Therefore, you can find much information regarding coriander, which has great importance almost in every field. Consequently, the coriander will be handled with the latest articles in details according to an order.

2. Methodology

The phytochemical constituents and pharmacological activities regarding the coriander and its essential oil have been investigated with the help of PubMed, Science Direct, Scopus, and Google. Generally, the latest articles were used when writing this review in this process.

3. Description of coriander

Coriandrum sativum L. (Coriander) is a member of the Apiaceae family (previously Umbelliferae) [9, 10] and known as cilantro, cilantrillo, Arab parsley, Chinese parsley, Mexican parsley, Dhania, and Yuen sai. It is an annual herb commonly used in Middle Eastern, Mediterranean, Indian, Latin American, African, and Southeast Asian cuisine [11]. Although cilantro and coriander seem to describe the same thing, it actually carries different meanings. When the plant is freshly harvested, the green leaves of the plant is called cilantro; if the dried fruits are used, the herb is called as coriander [12].

Figure 1. Coriander (The leaves and flowers from nature). Photo: M. Necat IZGI.

The plant grows all over the world [13], but originally from the Mediterranean regions, cultivated mainly in the tropical areas such as Ukraine, Russia, Romania, Morocco, Mexico, India, and Argentina [14]. Especially in a cool and comparatively dry frost, the free climate at the optimum temperature of germination and early growth of coriander is 20-25 °C. It grows best in dry climates, but it can grow in any type of soil like light, well-drained, moist, loamy soil, and light to the heavy black soil [15].

The genus Coriandrum L. (**Figure 1**) has been represented by two species in Flora of Turkey called C. sativum L. and C. tordylium (Fenzl) Bornm. [10]. C. sativum L. is coriander, approximately 30–100 cm in height, with strong-smelling leaves. It is cultivated as a domestic plant. In addition, in commerce, coriander has two varieties such as C. sativum L. var. microcarpum DC, the small-fruited species called as oil-rich Russian coriander and C. sativum L. var. vulgare Alef., the larger-fruited species with low oil content called as Moroccan, Indian and some other Asiatic types [16, 17]. The coriander has been described as glabrous aromatic, herbaceous, erect annual plant with a pronounced taproot, and slender branching stems up to 20–70 cm

in height. The leaves are lanceolate, green or dark green, glabrous on both surfaces and are variable in shape and lobed. The flowers are arisen in small umbels, white or light pink, asymmetrical, with the petals pointing away from the center. The coriander fruits are almost ovate globular dry schizocarp with two mericarps as usual and multiple longitudinal ridges on the surface possessing a sweet, slightly pungent, citrus-like flavor resembling sage [10, 17].

4. History of coriander

Coriandrum sativum L. has a long history as a culinary herb [17]. Sanskrit literature before 5000 BC and Greek Ebers Papyrus earlier 1550 BC have been mentioned from this herb. The coriander name comes from the "korannon," which is derived from the words "koris" and "annon" in Greece. By the way, the genus name as "Coriandrum" the first used by Pliny the Elder [18, 19]. It was said that the coriander seed emerged in the Neolithic level of the Nahal Hemel Cave in Israel. On the other hand, interestingly about one-half liter of coriander seeds was found in the tomb of Tutankhamun (Ramesses II) in Egypt. In Egypt, the herb was known as "spice of the happiness" may be attributed to its aphrodisiac property. In Greece, coriander seems to have been cultivated, since at least the second millennium BC, where the plant was used in perfumes and in cooking besides used as traditional medicine by Hippocrates [12, 19]. The herb was also widely used in the Roman Empire. As an example, Apicius (a collection of Roman cookery recipes) includes some 70 recipes using coriander in his cookbook. In Germany, coriander was used about ~900 AD [12]. The first factory to obtain the essential oil of coriander by the steam distillation was built in Russia in 1885 in the Voronezˇ district [20]. I came across a section regarding coriander written by Dioscorides in the literature. As shown below, Dioscorides emphasized how important it is [12]:

Dioscorides* wrote about *Coriandrum sativum*.

III. 63. κοριον The coriander: it has a cooling property, wherefore when plastered on with bread or barley groats, it cures erysipelas and shingles; with honey and raisins, it treats pustules that are most painful at night, testicular inflammations, and carbuncles; and with bruised corn, it dissolves scrofulous swellings of the glands and tumors. A small quantity of its seed drunk with grape syrup expels intestinal worms and furthers the production of semen, but if too much is taken, it dangerously disturbs the thinking process; this is why one must guard against drinking it to excess and continuously. Anointed with white lead or with litharge, and with vinegar and unguent of roses, the juice benefits surface tumors that are inflamed.

*Source: Beck LY, transl. Pedianius Dioscorides of Anazarbus. In: The Materia.

Medica: Ancient Scientific Texts and Studies, vol. 38 [in German]. Hildesheim,

Germany: Olms-Weismann.

5. Phytochemical constituents of coriander

Coriandrum sativum L. is a medicinal plant native to the eastern Mediterranean where it may have spread like many other aromatic plants to India, China and rest of the world [17]. In this frame, the essential oil is the main secondary metabolite of coriander. However, a different group of active substances will also be mentioned in present compilation.

The fruits contain sugars, alkaloids, flavones, resins, tannins, anthraquinones, sterols, and fixed oils [21, 22]. We can say that the most important constituents of coriander fruits are the essential oil and fatty oil [23]. The fatty acids in coriander fruits are petroselinic acid (*cis*-6-octadecenoic acid, 18:1), linoleic acid (18:2), oleic acid (18:1), and palmitic acid (16:0) [16, 17]. It was reported that coriander like all other green leafy vegetables is a rich source of vitamins (high amount of vitamin A/β-carotene: 12 mg/100 g and vitamin C: 160 mg/100 g) besides minerals and iron [24], very low in saturated fat and cholesterol and a very good source of thiamine, zinc, and dietary fiber. Unripen coriander contains 84% water [15]. Here, the most important phytoconstituents will be mentioned in the order.

5.1. Essential oils

There is much work to be performed collected from different localities of coriander essential oil. Because of the fact that, the coriander is one of the most important essential oil-bearing spices in its leaves, flowers, stem, seeds, roots, and bark; however, the composition of the parts can be different. Its chemical composition undergoes changes during ontogenesis, which affects the aroma of the plant, and thus interestingly the coriander fruit (seed) aroma is completely different from the aroma of the herb. Immature fruits and leaves have an unpleasant odor called a "stink bug smell" which is due to the presence of trans-tridecen in the oil [17]. On the other hand, the fragrance in the mature fruits pleasantly is similar to citrus peel and sage [16, 17]. By the way, Burdock et al. have mentioned about specifications of coriander oil according to the Food Chemical Codex (FCC) as given below [19]:

Characteristics	Metrics
Angular rotation	Between +8 and +15
Appearance	Colorless or pale yellow liquid
Heavy metals (as Pb)	Passes test
Identification	Infrared absorption spectrum
Odor	Characteristic of coriander
Solubility in alcohol	Passes test. 1 ml dissolves in 3 ml of 70% alcohol
Specific gravity	Between 0.863 and 0.875
Refractive index	Between 1.462 and 1.472 at 20°C

Coriander oil specifications according to the FCC, 2003 [19].
FCC = Food Chemicals Codex.

Coriander fruits contain about 0.2–1.5% of essential oil and 13–20% of vegetal oil (fixed oil); however, it has been recorded that some cultivars contain essential oil up to 2.6% [15, 25]. Another literature mentioned that coriander contains up to 1% essential oil where monoterpenoid linalool is the major compound (>50%), and limonene, camphor, and geraniol (**Figure 2**) are present in significant quantity [26]. Sometimes, the essential oil of the coriander obtained from the fruits was recorded approximately as 0.5–2.5%. It seems that different cultivars and

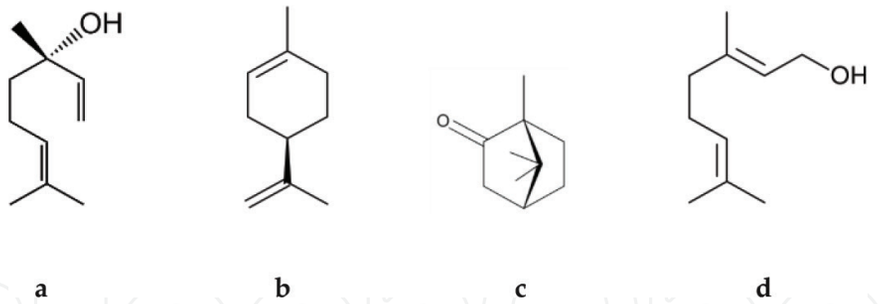

Figure 2. The major constituents in the essential oil of coriander fruit: (a) linalool, (b) limonene, (c) camphor, and (d) geraniol.

regions have been present in a different ratio of the essential oil concentration. However, in the majority of studies the main component is defined as linalool (60-70%) [16, 17]; sometimes up to 87.54%. In addition, α-pinene, camphor and geraniol are also known as other important components and are responsible for the character of fragrance and aroma of the plant. The investigation on two coriander varieties (*vulgare* and *microcarpum*) from Turkey has resulted in oil content like 0.15–0.25% in *vulgare* (linalool 42.1–52.7%); and 0.31–0.43% in *microcarpum* (linalool 63.5–71.0%) [9]. In Iran, the essential oil from the dried fruit of the coriander has been found in the range of 0.1–0.36% represented by 34 compounds, linalool (40.9–79.9%) as major component [27].

In a study, the essential oil of coriander was obtained by supercritical water extraction, hydrodistillation, and Soxhlet extraction methods. The main component found was linalool (82.916%) chosen as the key component to find the best-operating conditions [20]. In fact, the parameters exhibit different impact to reach the volatile oil; pressure and temperature control influenced the yield and composition. In an example, supercritical CO_2 fluid extraction to obtain the volatile oil from Italian coriander fruits was performed under different temperature conditions. A decrease in the particle size improved the volatiles' yield so as to more ducts were destroyed during the milling process. Optimum supercritical fluid extraction conditions were found to be as follows: Pressure 90 bar, temperature 40°C, 1.10 kg/h and 0.6 mm. The compositions of each supercritical fluid extraction samples were analyzed by GC and GC/MS. The major components were linalool (65–79%), the others γ-terpinene (4–7%), camphor (3%), geranyl acetate (2–4%), α-pinene (1–3%), geraniol (1–3%) and limonene (1–2%) [28]. Linalool was determined as the highest percentage composition in the essential oil of *C. sativum* fruit (73.11%) [29], but this rate can vary during different maturation periods. Essential oil obtained by hydrodistillation increased markedly during the maturation process, and geranyl acetate (46.27%), linalool (10.96%), nerol (1.53%) and neral (1.42%) were the major compounds at the first stage of immature fruits. At the middle stage, linalool (76.33%), *cis*-dihydrocarvone (3.21%) and geranyl acetate (2.85%) were reported as the main constituents. Essential oils at the final stage of maturity (mature fruits) include mainly of linalool (87.54%) and *cis*-dihydrocarvone (2.36%) [30]. In another study, the volatile oils of coriander have been compared each other by conventional methods such as hydrodistillation and solid-liquid extraction with methylene chloride and newer methods such as supercritical fluid extraction or subcritical water extraction which are safe environmentally. The highest crude extract was obtained by Soxhlet extraction and supercritical fluid extraction on the optimization conditions of 300 bar and 40°C (14.45% and 8.88%, respectively), while

subcritical water extraction on 100°C provided the lowest yield of lipid extract (0.36%). Similarly, the major compounds from coriander oil [γ-terpinene, (+)-limonene, linalool, camphor, and geraniol] were obtained by Soxhlet extraction (785.05, 26.73 and 21.96 mg/100 g of coriander fruits, respectively). By the way, subcritical fluid extraction provided extraction of vegetal oil, while polyphenolics were also extracted by subcritical water extraction, increasing health value of obtained extracts, and presenting good alternatives for traditional techniques [26]. Although the examples given are reproduced, the volatile oil content and their rates are almost the same.

5.2. Fatty acids

The vegetal oil (fixed oil/fatty oil) of coriander fruits, especially from French origin (23% yield), contain a high amount of monounsaturated fatty acids (1.8%); particularly petroselinic acid (73%) [22, 26]. The vegetable oil of coriander has been labeled as a Novel Food Ingredient (NFI), and it can be safely consumed as a food supplement by healthy persons, in maximum 600 mg/day dosages [22]. That is why, the essential oil of *C. sativum* fruits is called as triglyceride oil, due to the presence of petroselinic acid (**Figure 3**). The plant is recognized a potential source of lipids (rich in petroselinic acid) and essential oil (high in linalool) isolated from the fruits and the aerial parts [17]. The presence of petroselinic acid makes coriander more precious and interesting.

Petroselinic acid (18,1n-12) is classified as a monounsaturated the major omega-12 fatty acid exists in coriander oil, is a positional isomer of octadecenoic acid (its double bond being in position 6 instead of 9). Petroselinic acid has been detected at a level between 68 and 83% in coriander oil [31], or between 65–70% and 80.9% [9]. In a study, changes in fatty acids during maturation of coriander fruits cultivated in the North-East of Tunisia (Charfine) were studied. At full maturity, the main fatty acids were petroselinic acid (80.9 ± 5.7%), followed by linoleic (13.6 ± 2.9%), palmitic (3.6 ± 0.1%), and stearic (0.7 ± 0.1%) acids. During maturation of coriander fruit, saturated and polyunsaturated fatty acids decrease significantly, and monounsaturated fatty acids increase. It is necessary to underline that coriander fruits at the first four stages of maturity have a healthy nutritional value and the last five stages were with important economic and industrial applications [32, 33]. Commercial production of vegetable oils from oil-rich materials is based on through two traditional processes like the mechanical expression and extraction. In this manner, the maximum yield was obtained with single screw extruder for a configuration allowing the strongest oil expression. Comparing with a mechanical press, the maximum yield was obtained by the Soxhlet extraction with 21.25%, and the oil quality was found high grade. The acid value was under 1.8 mg of KOH/g of oil and iodine values were tolerable (44 mg of iodine/100 g of oil). In the oil, nine fatty acids were identified, with petroselinic acid accounting for 74–77% of the total fatty acids, followed by linoleic (12–13%), oleic (4–6%), and palmitic acids (3%). Moreover, *β*-sitosterol was the major sterol (28%) in all oils. The next major sterols in all oils were stigmasterol (24–27% of total sterols) and Δ^7-stigmasterol (14–18% of total sterols) [9, 34, 35].

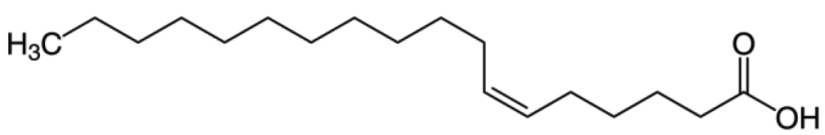

Figure 3. The structure of petroselinic acid.

5.3. Polyphenols

The polyphenols are very important secondary metabolites in coriander fruits and leaves because of their strong biological activities. Generally, flavones, tannins, and anthraquinones have been mentioned as the fruits phenolic constituents [21]. In coriander leaves, some phenolic compounds could be tentatively characterized using LC/MS. The polyphenol profile between leaves and fruits have been detected, and quercetin-glucuronide (**Figure 4**) was found as the major compound in plant parts, leaves and fruits [36]. Moreover, coriander leaves contain high amounts of caffeic, ferulic, gallic, and chlorogenic acids [12].

5.4. Carotenoids

Commercial varieties of coriander were analyzed by HPLC/MS and evaluated for carotenoids as β-carotene (vitamin-A precursor). In all varieties grown on similar conditions, β-carotene content was found higher in foliage at a mature stage, than in seedlings and seeds. For example, one of the varieties produced the highest biomass (6.18 ± 0.73 g/plant), total carotenoids (217.50 ± 5.6 mg/100 g DW) and β-carotene (73.64 ± 0.3 mg/100 g DW) at the pre-flowering stage. When the drying conditions are compared, microwave drying of foliage with oven drying one; the results showed that microwave drying protects pigments and trans-β-carotene [37]. The carotenoid content such as β-carotene (**Figure 5**), β-cryptoxanthin epoxide, lutein-5,6-epoxide, violaxanthin, and neoxanthin from the ether extract of coriander, the β-carotene was represented 61.14% of the carotenoids detected in the extract [38].

5.5. Isocoumarins

There are no recent articles regarding the isocoumarins from coriander. The isocoumarins, coriandrones A and B, together with coriandrin (**Figure 6**) and dihydrocoriandrin were isolated from the aerial parts of *C. sativum* [39]. In addition, coriandrones C-E were also isolated from the methanolic extracts of the aerial parts of the coriander cultivated in the botanical garden of the Osaka University of Pharmaceutical Sciences [40]. Extracts of coriander were analyzed for photoactive constituents using HPLC and photobiological assay. Similarly, photoactive furoisocoumarins named as coriandrin and dihydrocoriandrin were also obtained, and their structures determined by ^{1}H, ^{13}C NMR and X-ray crystallography [41].

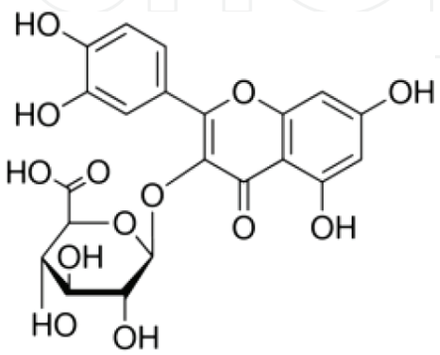

Figure 4. The structure of the quercetin-glucuronide.

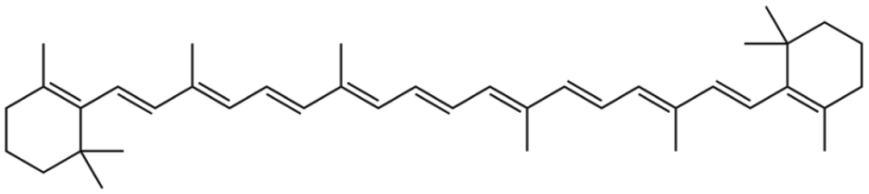

Figure 5. The structure of β-carotene.

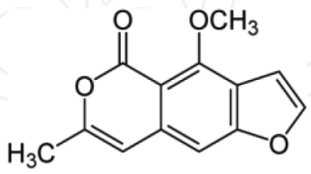

Figure 6. The structure of coriandrin.

6. Biological activities and usages of the coriander

In the food industry, coriander is approved in food-use by the Food and Drug Administration (FDA in the USA), the Flavor and Extract Manufacturers Association and the Council of Europe. The plant can be mainly used as a spice, medicine, and raw material in food, beverage and pharmaceutical industries [16, 17]. Microwave-drying characteristics of coriander leaves were examined in designing and modeling heat and mass transfer processes during storage and other possible operations, necessary in food and chemical industry [42]. Moreover, the encapsulation (400 nm–7 μm) of the essential oil of coriander with chitosan obtained from the waste shells of crayfish (*Astacus leptodactylus*) has been arranged via the spray drying method led to the much higher antimicrobial activity and antioxidant activity than the oil and the pure chitosan. The created product could be beneficial in the food and pharmaceutical industries as a natural antioxidant and antimicrobial agent [43]. One of the reasons for being famous as a spice in the food industry is to use as a common flavoring substance for the pleasant aromatic odor of their stems, leaves, and fruits. That is why it is used in seasonings for sausages, and other meat products besides in baked goods, beverages, sweets, chewing gums, tobacco products, condiments, preservative, and also functions as an essential ingredient in curry powder. On the other hand, it should not be forgotten that coriander and its oil are used especially in perfumery and cosmetics. The warm and sweet notes of coriander oil mixed with other floral notes for oriental type perfumes have a different effect. It is used not only in perfumes but also in soaps, creams, lotions and in aromatherapy as much as covering the taste of some medicines [19]. The leaves are used for flavoring curries, sauces, and soups, while the whole young plants are used for preparing chutneys. All parts of *Coriandrum sativum* are edible and used as a spice in daily life [44]; however, its fresh leaves and dried fruits are the most frequently used parts. Green foliage, known to be rich in proteins, vitamins, and minerals (such as calcium, phosphorus, and iron), fibers and carbohydrates, are reportedly used as vegetables in salads. While the coriander fruits are very popular as health-supporting as the healing spices, the essential oil of coriander can be marketed as a food supplement at a maximum dosage of 600 mg per day. On the other hand, the fruits are a rich source of lipids (fatty acids) (28.4%), which may be of great

importance in the food industry. Petroselinic acid (18:1), linoleic acid (18:2), oleic acid (18:1), and palmitic acid (16:0) are valuable fatty acids of coriander fruits [16, 17]. Petroselinic acid is an important fatty acid to show substantial biological effects. It significantly increased the production of anti-inflammatory precursor and decreased pro-inflammatory precursor [13], and it has the capability to the reduction of arachidonic acid in the heart and liver of rats. When petroselinic acid was orally administered, the overproduction of arachidonic acid has been restricted [45]. Moreover, it has antimicrobial properties and can be a competitive inhibitor of topoisomerases; therefore, it is a potential agent in the treatment of cancer [46]. Topoisomerases modify the structure of DNA and play a role in the progression of several proliferative diseases [45]. In addition, the major components of the essential oil of coriander, linalool has antioxidant, anticancer, neuroprotective, anxiolytic, anticonvulsant, relieving migraine, analgesic, hypoglycemic, hypolipidemic, blood pressure lowering effects [47]. A syrup prepared by the ethanolic extract of the coriander fruits exhibited short-term considerable effects on migraine reducing duration and frequency of the migraine attacks and diminishing pain degree, in a month [48].

In short, coriander fruits and its oil have been used for many diseases [13] such as for the treatment of rheumatism, gastrointestinal upsets, insomnia, flatulence, and joint pain in humans [49]. Moreover, coriander has a positive influence on lipid profile in plasma of rats [50]. The hydroalcoholic extract of the coriander fruits has exhibited anti-inflammatory, and anti-granuloma properties are reducing TNF-R1 expression on peritoneal macrophages in an experimental model [51]. The fruits of the plant are famous for carminative, diuretic effects and used in the treatment of cold, fever, nausea, and stomach disorders [16]. The fruit extract has been found as a strong analgesic agent than dexamethasone [52]. Laribi et al. discussed with all aspects regarding the pharmacological effects of coriander in a review [9]. In this manner, the most frequent effects of coriander will be debated in an order.

6.1. Antioxidant effects

The antioxidant potencies of polyphenolic compounds from *Coriandrum sativum* against hydrogen peroxide-induced oxidative damage in human lymphocytes have been investigated in some articles. It was seen that the treatment with polyphenolic fractions (50 μg/mL) was increased the activities of antioxidant enzymes (superoxide dismutase, catalase, glutathione peroxidase, glutathione reductase, and glutathione-S-transferase) and glutathione content. On the other hand, it reduced the levels of TBARS significantly [53]. The aqueous coriander extracts (2.734 mg) of total phenolics (catechin equivalents) per 100 g of a dry sample exhibits considerable antioxidant activity according to the *β*-carotene/linoleic acid model. The caffeic acid (4.34 and 2.64 mg/mL), protocatechuic acid and glycitin (6.43 and 3.27 mg/mL) were found in high concentration in the aqueous extract [54]. Moreover, it seems that subcritical water extraction showed significant improvement comparing the yields of phenolics and flavonoids obtained with this technique against conventional solid-liquid extraction and modern extraction techniques, such as ultrasound-assisted and microwave-assisted extraction. When the temperature, pressure and extraction time were optimized, the highest yields and lowest IC_{50} were observed. Total phenolics and total flavonoids content were maximized, while IC_{50} value was minimized, and optimum conditions were determined using desirability function. The most efficient extraction conditions for all three responses were the temperature of 200°C, the pressure of 30 bar and extraction time

of 28.3 min [55]. In another study, the hot water extract of the coriander fruits has been evaluated for their antioxidant characters [56]. The aerial parts of the hydroalcoholic extract of *C. sativum* showed important antioxidant activity besides anticonvulsant effects [57]. The antioxidant activity of the essential oil of coriander conducted by different types of antioxidant tests have been investigated, and the total phenolic content of the sample is found the 52.3 mg GAE/L [17, 58].

The potency of the antioxidant activity of coriander is indeed attributed to its carotenoid content. Carotenoid extract of the coriander showed high antioxidant activity with an IC_{50} value of 14.29 ± 1.68 μg/mL, scavenging hydroxyl radicals and providing higher protection to DNA than by standard gallic acid (IC_{50} = 357.21 ± 4.29) [37]. It was seen that there was a synergistic action between the carotenoids compared to the crude extract [38]. Obviously, the aqueous or alcoholic extracts of the coriander have significant antioxidant capacity depending on the polyphenolic content. Carotenoids in coriander show higher antioxidant capacity in the extracts.

6.2. Antimicrobial effects

The antimicrobial activity of the coriander has been arisen from the essential oil content. The essential oil of coriander has been exhibited potent antimicrobial activity against oral pathogens, and a dental gel formulation [59]. Moreover, the aqueous extract of coriander was found to have potency against acne-inducing bacteria (MIC values are 1.7 mg/mL for *Propionibacterium acne* and 2.1 mg/mL for *Staphylococcus epidermidis*). The formulations commercially developed for the treatment of acne, showed the same activity [60]. The development of advanced anti-acne formulations, the coriander oil is the good options due to the antibacterial activity [61]. Coriander is also found as an important herbal remedy for its antioxidant, anti-inflammatory, analgesic and antimicrobial properties of diaper dermatitis which is a common dermal disorder [62]. Moreover, coriander oil exhibited powerful activity against *Bacillus cereus, Enterococcus faecalis, Staphylococcus aureus, Pseudomonas aeruginosa, Klebsiella pneumoniae, Escherichia coli, Salmonella typhi,* and *Acinetobacter baumannii* with different degrees of inhibition. *Bacillus cereus* was the most sensitive strain along with one of the multidrug-resistant clinical strains of *Acinetobacter baumannii* (MIC 50.1%, v/v), while *P. aeruginosa* was the most resistant to growth inhibition by the tested oil, showing the highest determined MIC (1.6%, v/v), with the exception of *B. cereus* and *E. faecalis*. On account of this, the use of coriander oil can be encouraged in antibacterial formulations owing to the fact that coriander oil effectively kills pathogenic bacteria related to foodborne diseases and hospital infections [63]. In many studies, coriander essential oil was investigated for the antibacterial and antifungal activity and has been found a good potency of the antimicrobial activity [17, 58, 64]. The antifungal activity of the essential oil obtained by hydrodistillation from *Coriandrum sativum* has been examined against different *Candida* species and exhibited antifungal activity against all tested species of *Candida*, except for *C. tropicalis* CBS 94. Hence, it was concluded that the oil could be used as potential antimicrobial agents to treat or prevent *Candida* yeast infections [65]. In another study, the essential oil of *C. sativum* leaves growing in Kenya showed antimicrobial activity against clinical isolates of Gram (+) (*S. aureus, Bacillus* spp.) and Gram (−) (*E. coli, Salmonella typhi, K. pneumoniae, Proteus mirabilis, P. aeruginosa*) bacteria but not a pathogenic fungus, *C. albicans* [66]. It was observed that the fruit oil of coriander displayed very good activity against *S. aureus*, *S. haemolyticus*, *P. aeruginosa*, *E. coli*, and *Listeria monocytogenes* [12].

In addition, the coriander essential oils which are obtained by hydrodistillation and microwave-assisted hydrodistillation have been compared for their antimicrobial potency. No distinctive activity differences were found except for energy and time savings [67].

6.3. Antidiabetic effects

In many articles, we can find the antidiabetic effects regarding the coriander. In fact, coriander has been confirmed as an antidiabetic remedy. The studies have confirmed the antihyperglycemic effect of coriander in streptozotocin-diabetic mice. The mechanism of action of the antihyperglycemic action of the aqueous extract of the coriander fruits is connected with stimulation of insulin secretion, enhancement of glucose uptake and metabolism by muscle. In general, the effect is generated by one or more components existed in the extract. Therefore, *C. sativum* is acceptable as a possible antihyperglycemic dietary supplement and can be accounted for a potential source of a new orally active agent for diabetes [68]. In another study, a single dose of coriander fruit-extract or glibenclamide suppressed hyperglycemia in obese–hyperglycemic–hyperlipidemic *Meriones shawi* rats. After administration, the insulin resistance significantly decreased in the rats. Interestingly, the hypoglycemic effect was lower in normal rats, its mean; the test substances reduced plasma glucose, insulin and insulin resistance, cholesterol, LDL-cholesterol, and triglyceride [69]. Moreover, it was observed that a dose of coriander fruit decrease and regulate blood sugar and dyslipidemia at typical traditional doses in the patients who have noninsulin-dependent diabetes mellitus. In a study of 40 volunteers, 20 subjects took 2.5 g of ground coriander fruit twice daily for 60 days and 20 volunteers served as controls. The treatment group had a significant declining in fasting blood-sugar levels; a significant reduction in lipid peroxidation in red blood cells; and rises in serum β-carotene, vitamin A, vitamin C, vitamin E, and glutathione levels [12]. In addition, the animals in the two groups showed almost similar weight gain, and the diet consumption was similar in both groups. There is a significant decrease in fasting blood glucose level and increase in the concentration of hepatic glycogen in the rats of the experimental group. Hexokinase and phosphoglucomutase activity increased significantly in the liver of rats administered coriander fruits. The glycogen synthase activity in the liver was increased, and that of glycogen phosphorylase showed a decrease in the rats of the experimental group compared to the control group. Significant reduction in glucose-6-phosphatase activity was observed in the experimental group, whereas glucose-6-phosphate dehydrogenase activity showed a significant increase [70]. In this frame, coriander, especially the fruits of the plant found in the receipts can be also acceptable for the treatment of hepatic fibrosis and chronic liver diseases [71].

6.4. Anxiolytic effects

The aqueous extract of coriander fruits has an anxiolytic activity and may possess sedative and muscle relaxant effects dose-dependently in mice. Its utility in clinical applications may be similar to that of diazepam. The effect of coriander at a dose of 100 mg/kg in mice was found almost equivalent to that of 0.3 mg/kg diazepam on the plus-maze test. According to the studies on animal and on human, 7.5 g dry extract of coriander fruit may be suggested as effective dose for a 75 kg adult man. This corresponds to an infusion of approximately 20 g of coriander fruit in 100 mL water, considering the yield of the extract in the range of the coriander doses, tentatively used in traditional medicine. However, the effect of the extract in a clinical application was not determined to reach the optimum therapeutic dose for a human [49].

For example, the aqueous extract of coriander fruits (200, 400, and 600 mg/kg per day), alcohol extracts (400 and 600 mg/kg per day), and essential oil (600 mg/kg per day) increased pentobarbital-induced sleeping time. In a mouse study, coriander fruits (50, 100, and 200 mg/kg) was compared with diazepam (0.5 mg/kg) in animal models of anxiety. Coriander fruits were almost recorded equivalent to diazepam as an anxiolytic at the two higher doses [12].

6.5. Cardioprotective effects

The hydro-methanolic extract of coriander fruits has been found cardioprotective potential. This effect should be attributable to its high polyphenol content in the fruits likewise. The preventive effect of coriander on cardiac damage has been investigated by isoproterenol induced cardiotoxicity model in male Wistar rats and found that the methanolic extract of the fruits prevent myocardial infarction by inhibiting myofibrillar damage on rats [72]. The coriander fruits caused a significant decrease in all cholesterol-associated lipids, while the extract reduced high-density lipoprotein (HDL) cholesterol; the extract also improved the cardioprotective indices. Coriander fruits also reduced dyslipidemia in rabbits. All blood-fat values improved significantly with the coriander diet. It means that the extracts have beneficial profits on cardioprotective effect [12].

6.6. Anthelmintic effects

The anthelmintic activities (*in vitro*) of crude aqueous and hydroalcoholic extracts of the fruits of *Coriandrum sativum* were investigated on the egg and adult nematode parasite called as *Haemonchus contortus* and the aqueous extract of coriander for *in vivo* anthelmintic activity in sheep infected with *Haemonchus contortus*. Both extract types inhibited completely leaving eggs at a concentration less than 0.5 mg/mL. ED_{50} of aqueous extract was found 0.12 mg/mL while that of the hydroalcoholic extract was 0.18 mg/mL [73]. Moreover, all essential oil dosages showed a significant level of toxicity to the *Sitophilus granarius* (an insect) after 5 days in chickpea grains [29].

6.7. Antiulcer effects

Coriander is a potential herb to protect the body against absorption of heavy metals and other dietary toxins. Moreover, the herb can be able to prevent the formation of gastric ulcers and *Helicobacter pylori.* In a study, the antigastric ulcer and antisecretory activity of coriander have been confirmed and concluded that the effect might be linked to the antioxidant property of different constituents present in Coriander, involved in scavenging of the reactive oxygen species on the surface of gastric mucosa, or might also form a protective layer by hydrophobic interactions. That is why, it protects the cells from gastric injury [74]. In a recent work, the animal study showed that coriander fruits (250 mg/kg and 500 per os) protected the animals against the ulcerogenic effects of salt, sodium hydroxide, ethanol, indomethacin, and pylorus ligation dose-dependently [12].

6.8. Antiaging effects

The long chain fatty acids are potentially beneficial in antiaging products for local use, helping to restore barrier properties of the epidermis and prevent moisture loss. Therefore, the long chain fatty acids can be considered as potential antiaging agents. Coriander fruit oil is very

rich in these types of the fatty acids. The studies done as a topical treatment for a variety of skin conditions with coriander-fruit oil and as a component of herbal sunscreens seem very impressive [12]. The oil may contain ceramides of petroselinic acid as well. The extract also functions as an anti-irritant and helps to maintain skin texture and tone. A specially prepared extract from coriander fruits such as Umbelliferin® (INCI: *Coriandrum sativum* (coriander) extract is a trademarked product containing petroselinic acid triglycerides obtained as a nonlauric fraction from coriander fruit oil) helps in supporting skin barrier functions [45]. Preparations using coriander/oil as single form or in combination with the other plants can be developed in the future and may become famous as one of the secrets of staying young for a long time.

6.9. Anticancer effects

The biochemical effect of coriander fruits on lipid parameters in 1,2-dimethylhydrazine induced colon cancer has been studied in rats. The concentrations of cholesterol and cholesterol to phospholipid ratio declined while the level of phospholipid increased significantly in 1,2-dimethylhydrazine control group compared to the coriander administered group. Fecal dry weight, fecal neutral sterols, and bile acids showed a sharp increase in the coriander-fed group compared with the DMH-administered group. Thus, it seems that the coriander plays a protective role in the lipid metabolism of colon cancer [75]. Although there are not many studies on the anticancer effect of coriander, there are some studies based on antioxidant effect.

6.10. Diuretic effects

There is no more study on diuretic effect of coriander to mention in this compilation. In a study, the aqueous extract of coriander fruits was implemented by continuous intravenous infusion (120 min) at two doses (40 and 100 mg/kg) under anesthetize conditions. A diuretic-Furosemide (10 mg/kg) has been used as the standard drug. In the assay, water and electrolyte excretion (sodium, potassium, and chloride) were measured in urine, and glomerular filtration ratio (equal to creatinine clearance) was determined. The crude aqueous extract of coriander fruits increased diuresis, excretion of electrolytes, and glomerular filtration rate in a dose-dependent way; but furosemide was found more potent as a diuretic and saluretic. By the way, the mechanism of action of the plant extract appears to be similar to that of furosemide. In Moroccan pharmacopeia, the coriander is listed and indicated that the aqueous extract of coriander fruits has diuretic and saluretic activity verifying the use of coriander as a diuretic plant [11].

7. Coriander in traditional medicine

All parts of this herb are in use as a flavoring agent (culinary purposes) and/or as traditional remedies for the treatment of different ailments in the folk medicine on different civilizations [15, 76] especially in digestive disorders. The fruits of this herb are very popular as a spice in Mediterranean countries [9]. Hippocrates (460–377 BC) used coriander in ancient Greek Medicines. Decoction and tincture of powdered fruits of *C. sativum* alone or in combinations

with other herbals are recommended for dyspeptic complaints, loss of appetite, convulsion, insomnia, and anxiety. Coriander essential oil has also a long history in traditional medicine. The essential oil was found to improve blood glucose control and promise as an antihyperglycemic (antidiabetic) agent [17]. On the other hand, the aqueous extract of coriander fruits is used in traditional Moroccan medicine in the treatment of diabetes and dyslipidemia besides to treat a variety of disorders [69] including Saudi Arabia and Jordan [9]. In addition, Moroccan and Palestinian pharmacopeias have been mentioned the usages of coriander as a traditional diuretic and treat urinary infections [15]. In Iranian traditional medicine, coriander fruits have a long history of use as an anxiolytic and a sedative in insomnia. The fruits were widely used internally as a carminative, digestive, spasmolytic, and galactagogic as usual. Moreover, it is also known as an anti-inflammatory agent in Iranian traditional medicine, still in herbal formulations, might be beneficial in human inflammatory bowel diseases [77]. Coriander is highly reputed Ayurvedic medicinal plant commonly known as "Dhanya" in India [15]. Usage of coriander leaves is not clear on diabetes as suggested on Persian folklore medicine, but Ayurvedic medicine also recommends the regular use of a decoction of coriander fruits (seeds) and mentioned about effects in the treatment of arthritis and other inflammatory disorders [9, 12]. Anyway, it is the main ingredient in curry powder in Indian food; the fresh green leaf is dominated in Thai and Vietnamese foods. Moreover, the roots of coriander have been used in Asian cuisine for intense flavor [9]. Moreover, in some regions of India, the plant has been used traditionally for its "anti-inflammatory" principals; besides, the fruits are used to treat spermatorrhea, leucorrhea, and rheumatic fever [16, 78].

In the United States, coriander has recently been studied for its cholesterol-lowering effects [16]. Moreover, in some parts of Europe, coriander has traditionally been referred to as an "antidiabetic" plant [16, 78]. In Pakistan, the whole plant part is used for the treatment of flatulence, dysentery, diarrhea, cough, stomach complaints, jaundice, and vomiting. In Turkey, it is noted that the fruit infusions are useful in indigestion and as an appetizer [9]. However, in history, it is mentioned that coriander has an aphrodisiac effect as many other spices [78].

In traditional medicine, the usual dose of fruit powder is from 1 to 5 g, three times per day. This translates to a 43–71 mg/kg dose for a 70 kg individual [12]. Most of the traditional usages of the coriander have been supported by scientific data as mentioned in the text. This point is very important that the plant has been integrated between traditional and scientific usages.

8. Toxicity of coriander

Coriander fruits at a dose of 750 mg/kg caused no mortality in rats, and LD_{50} (lethal dose that kills 50% of test subjects) for the oil was found 4.13 g/kg. However, high doses of coriander fruits (500 mg/kg) inhibited implantation in female rats significantly and had a small abortifacient (but no teratogenic) effect on the rats. In the Ames test, a dried leaf extract produced a mutagenic effect [12]. By the way, coriander juice extracts were neither toxic nor mutagenic in the range of concentrations tested (50–1000 μL/coincubation flask); the chlorophyll content in whole juice extracts was 0.0325 μg/mL [79].

9. Conclusion

The new attraction for natural products like essential oils is important to develop a better understanding of their mode of biological action for new applications in human health, agriculture, and the environment. The essential oils could find many applications as an ingredient in different industries, like the cosmetic, the pharmaceutical, and the food industries. Updates on coriander usefulness, based upon the scientific studies, have been given in this compilation, with emphasis on its essential oils. The coriander as an aromatic plant is an edible herb, famous spice, and nontoxic to humans. The healing properties of coriander can be attributed to exceptional phytochemicals. Considering these potentials of coriander and its biomolecules can be significant along with a tremendous future. The essential oil of coriander is also rich in beneficial phytonutrients, and the fruits have a health-supporting reputation that is almost on the top of the list of the healing spices besides many other traditional health benefits mostly supported by scientific reports. The other uses of coriander are amazing, but information on their possible benefits remains ambiguous. By the way, exciting essential and fatty oil combination in a magical proportion in the fruit composition makes the plant still worthy of future investigations and utilization. Finally, it is strongly recommended that coriander is an incredibly safe herb, and it would be beneficial to increase coriander use in diet.

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