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Coriander (*Coriandrum sativum* L.) essential oil: chemistry and biological activity

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ABSTRACT

Coriandrum sativum L. (*C. sativum*) is one of the most useful essential oil bearing spices as well as medicinal plants, belonging to the family Umbelliferae/Apiaceae. The leaves and seeds of the plant are widely used in folk medicine in addition to its use as a seasoning in food preparation. The *C. sativum* essential oil and extracts possess promising antibacterial, antifungal and anti-oxidative activities as various chemical components in different parts of the plant, which thus play a great role in maintaining the shelf-life of foods by preventing their spoilage. This edible plant is non-toxic to humans, and the *C. sativum* essential oil is thus used in different ways, *viz.*, in foods (like flavoring and preservatives) and in pharmaceutical products (therapeutic action) as well as in perfumes (fragancias and lotions). The current updates on the usefulness of the plant *C. sativum* are due to scientific research published in different web-based journals.

1. Introduction

The essential oils and extracts of aromatic plants and spices have been used in food preservation, pharmaceuticals, alternative medicine and natural therapies. Currently, it is necessary to investigate those plants scientifically, for the composition of essential oil (EO) and its biological activities, which have been used in traditional medicine to improve the quality of healthcare. The EO contents in different species are varied inherently, influenced greatly by culture conditions and environment, as well as by crop and post-crop processing, and hence evaluations of the oils from many medicinal plants are being conducted. One of the most useful EO bearing spices as well as medicinal plants is *Coriandrum sativum* L. (*C. sativum*) (containing EO in its leaves, stem, flowers and fruits/seeds), and thus updates on its usefulness, based upon the scientific studies, are required for its better maintenance and scientific use for the mankind.

Coriander (*C. sativum* L.) belonging to the family Umbelliferae/Apiaceae is a glabrous aromatic, herbaceous annual plant, which has a long history as a culinary herb being the source of aroma compounds and EOs with biologically active components possessing antibacterial, antifungal and antioxidant activities, and thus *C. sativum* is useful in food preparation (as a flavoring agent and adjuvant) and preservation as well in preventing food borne diseases and food spoilage.

C. sativum provides two types of herbal raw materials— fruits and leaves, the main biologically active substance of which is EO. Coriander will be seeds and added to dishes as an aromatic spice, which at the same time act as digestive agent accelerating the digestion process. The yield of *C. sativum* EO and its chemical composition undergoes changes during ontogenesis[1], which affects the aroma of the plant, and thus the coriander fruit aroma is completely different from the aroma of the herb[2]. Immature fruits and leaves have an unpleasant odour called a “stink bug smell” which is due to trans-tridecen contained in the oil.

Coriander is referred to as “kusthumbari” or “dhanayaka” in

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the Sanskrit literature; in Hindi it is called Dhania, while Dhane in Bengali. It is a native plant of the eastern Mediterranean from where it may have spread to India, China and rest of the world[3]. In the food industry, coriander is approved for food use by the US Food and Drug Administration, the Flavor and Extract Manufacturers Association and the Council of Europe, and the plant can be used as spice, medicine and a raw material in food, beverage and pharmaceutical industries.

2. Botanicals

The *C. sativum* L. (family Umbelliferae/Apiaceae) is an erect annual herb with pronounced taproot, and slender branching stems up to 20-70 cm in height. There are two varieties of *C. sativum*: *vulgare* and *microcarpum*; the former has larger fruits (3-5 mm diameter) with EO yields of 0.1%-0.35% (v/w) while the latter has smaller fruits (1.5-3 mm diameter) with EO yields of 0.8%-1.8% (v/w)[4]. However, Ravi *et al.*[5] documented that the weight of 1000 fruits, with fruit diameter > 3 mm, is > 10 g for *C. sativum* L. var. *sativum*, while for *C. sativum* L. var. *microcarpum* DC, the weight of 1000 fruits is < 10 g, with fruit diameter × 3 mm.

The leaves are lanceolate, green or dark green, glabrous on both surfaces and are variable in shape and lobed. The flowers are borne in small umbels, white or light pink, asymmetrical, with the petals pointing away from the centre. The coriander seed (Figure 1), is almost ovate globular dry schizocarp with two mericarps[6], and multiple longitudinal ridges on the surface possessing a sweet, slightly pungent, citrus like flavor with a hint of sage[3].

Figure 1. Dry coriander, *C. sativum* seeds: halves and whole.

3. Usage and nutritional value

All parts of *C. sativum* plant are edible; however, its fresh leaves and dried seeds are most frequently used. Its green foliage, containing proteins, vitamins and minerals (like calcium, phosphorus, and iron), fibres and carbohydrates, is used as vegetable, and in salads, while both the leaves and seeds contain EO, rich in varying components, which provides typical flavour, when added to the food products and acts as preservative[7].

The *C. sativum* seed EO (CSEO) is triglyceride oil; petroselinic acid, a monounsaturated fatty acid, is the major fatty acid in CSEO. Thus, the plant is a potential source of lipids (rich in petroselinic acid) and EO (high in linalool) isolated from the seeds and the aerial parts. Ganesan *et al.*[8] reported that matured coriander leaves are rich in moisture (87.9%), protein (3.3%), carbohydrate (total sugar 6.5%) and total ash (1.7%). The CSEO is intended to be marketed as a food supplement for healthy adults, at a maximum level of 600 mg per day[9]. The seeds are rich source of lipids, 28.4% of the total seed weight, which may be of great importance in the food industry[6]. The typical compositional analysis of coriander oil is shown in (Table 1)[10].

Coriander EO also has a long history of use as a traditional medicine[4]. Coriander was used in time-honored Greek medicines by Hippocrates (460-377 BC). Decoction and tincture of powdered seeds of *C. sativum* alone or in combination with other herbal agents are recommended for dyspeptic complaints, loss of appetite, convulsion, insomnia and anxiety[11]. This CSEO was also found to improve blood glucose control and thus it held promise for use as an anti-hyperglycemic agent[12].

4. EO chemistry

The EO can be extracted from various parts of plants including the leaves, flowers, stem, seeds, roots and bark; however, the composition of the EO can vary among different parts of the same plant, such as, EO obtained from the *C. sativum* seed has different composition from the EO of *C. sativum* flower as well as cilantro (immature leaves) (Table 2). The *C. sativum* oil from fully ripe and dried seeds is a colorless or pale yellow liquid with a characteristic odour and mild, sweet, warm and aromatic flavour, and linalool is its major constituent[4]. While aliphatic aldehydes (mainly C10-C16 aldehydes), with their unpleasant odour, are the main components of the volatile oil from the fresh herb[13], linalool and other oxidized

Table 1
The compositional analysis of *C. sativum* essential oil[10].

Chemical group	Composition
Alcohols	Linalool (60-80%), geraniol (1.2%-4.6%), terpinen-4-ol (3%), -terpineol (0.5%)
Hydrocarbons	γ-terpinene (1-8%), r-cymene (3.5%), limonene (0.5%-4.0%), a-pinene (0.2%-8.5%), camphene (1.4%), myrcene (0.2%-2.0%)
Ketones	Camphor (0.9%-4.9%)
Esters	Geranyl acetate (0.1%-4.7%), linalyl acetate (0%-2.7%)

Table 2

Composition variation of *C. sativum* essential oil from different parts of the plant

Source	Composition	Geographic location	Reference
Seeds	Linalool (58.0-80.3%), γ-terpinene (0.3%-11.2%), -pinene (0.2%-10.9%), p-cymene (0.1%-8.1%), camphor (3.0%-5.1%) and geranyl acetate (0.2%-5.4%)	Europe	[49]
Flowers	Benzofuran,2,3-dihydro (15.4%), hexadecanoic acid, methyl ester (10.32%) 2,4a-epioxy-3,4,5,6,7,8,-hexahydro-2,5,5,8a-tetramethyl-2h-1-benzofuran (9.35%), 2-methyoxy-4-vinylphenol (8.8%)2,3,5,6-tetrafluroanisole (8.62%) 2,6-dimethyl-3- aminobenzoquinone (6.81%) dodecanoic acid (5%)	India	[50]
Leaves	Decanal (19.09%), trans-2-decenal (17.54%), 2-decen-1-ol (12.33%) and cyclodecane (12.15%), cis-2-dodecena (10.72%), Dodecanal (4.1%), dodecan-1-ol (3.13%)	Brazil	[34]

monoterpenes as well as monoterpene hydrocarbons predominate in the oil distilled from the fruit[1].

Coriander fruit contains about 0.2%-1.5% of volatile oil and 13%-20% of fat oil[14]; however, it has been recorded that some cultivars contain up to 2.6% of volatile oil[15]. As has been reported by Zawislak[16], the EO content ranged 1.87%-2.33%. The fatty oil composition of ripe fruits mainly includes petroselinic acid (68.8%), linoleic acid (16.6%), oleic acid (7.5%) and palmitic acid (3.8%) [15]. The hydro-distillation of *C. sativum* L. aerial parts gave EOs at vegetative, full flowering, green fruit (immature) and brown fruit (mature) with a yield of 0.14%, 0.23%, 0.37% and 0.31% (w/w), based on dry weight, respectively[17].

There is variation in seed yield and EO content of *C. sativum* cultivars grown at different locations. The EO content in *C. sativum* fruits is very different, 0.5%-2.5%[18], and it increases as the fruit ripens[19], while *C. sativum* leaves contain less EO than the fruit. The *C. sativum* leaves from Bangladesh had 0.1% EO[1], and the plant harvested in Tunisia contained 0.12% EO in leaves dried in air[2]. The amount of EO in the coriander herb was on average 0.23 mL per 100 g, and it was higher in the generative phase (0.29 mL per 100 g) than in the vegetative phase (0.17 mL per 100 g)[20].

Variation is there in the EO yield of *C. sativum* fruits from different origins (Table 3). The hydro-distillation of *C. sativum* L. aerial parts gave EOs at vegetative, full flowering, green fruit (immature) and brown fruit (mature) with a yield of 0.14%, 0.23%, 0.37% and 0.31% (w/w), based on dry weight, respectively[17]. The chemical class characters of *C. sativum* EOs from different fruit samples have been represented by Sriti *et al*.[21]: monoterpene hydrocarbons (16.2%-20.7%), monoterpene alcohols (59.4%-73.8%), monoterpene esters (3.7%-9.1%), aldehydes (0.3%-0.9%), ketones (3%-6.5%) and phenols (0.06%); the polyphenol contents varied from 15.16 mg GAE/g to 12.10 mg GAE/g. The C. satvium seeds yielded 0.8%, by weight, yellow oil, with a pleasant aroma, containing oxygenated monoterpenes (80.47%), monoterpene hydrocarbon (6.45%), fatty acids (5.06%) and long chain alcohols (3.54%), as has been reported by Pande *et al*[22].

Table 3

Yield of essential oil of *C. sativum* from different geographical regions.

Coriander origin	Coriander part	Essential oil yield (%)	Reference
Tunisia	Fruit	0.37	[21]
Canada	Fruit	0.44	[21]
Egypt	Fruit	0.31	[51]
Turky	Fruit	0.43	[52]
India	Fruit	0.82	[5]

The raw coriander consisted mainly of linalool (72.7%) followed by λ-terpinene (8.8%), α-pinene (5.5%), camphor (3.7%), limonene (2.3%), geranyl acetate (1.9%) and p-cymene (1.5%)[23]. The oil composition changes, depending on the maturity of the seed. The researchers[19,22,24] have represented variation of *C. sativum* EO composition in developmental stages (Tables 4 and 5). The chemical

Table 4

Differences in the essential oil content of *C. sativum* seeds at different developmental stage (Msaada 2009: text data converted)[24].

Stage of development	EO composition
First stage	Linalool (36%), geranyl acetate (35%), assorted mono- and sesquiterpenes (trace amounts)
Second stage	Linalool (40%), geranyl acetate (8%), camphor (4%), menthol (3%), other mono- and sesquiterpenes (trace amounts)
Third stage	Linalool (45%), monoterpene esters excluding geranyl acetate (22%); mono- and sesquiterpene hydrocarbons (*viz*., limonene) and ketones (*viz*., camphor) in reduced amounts
Fourth stage	Monoterpene alcohols (78%): linalool (72%), monoterpene hydrocarbons (5%), mnoterpene esters (2%), monoterpene ketones (1%)

Table 5

Composition of *C. sativum* essential oil of fruits harvested at different stages of maturity from two geographical regions.

Origin	Stage of maturity	Compound	Reference
Uttarakhand State (India)	First stage (immature fruits)	Geranyl acetate (46.27%), linalool (10.96%), nerol (1.53%), neral (1.42%)	[22]
	Middle stage (intermediate fruits)	Linalool (76.33%), cis-dihydrocarvone (3.21%), geranyl acetate (2.85%)	
	Final stage (mature fruits)	Linalool (87.54%), cis-dihydrocarvone (2.36%)	
Tunisia	First stage (immature fruits)	Monoterpene esters (46.27%), monoterpene alcohols (14.66%), monoterpene aldehydes (2.07%), monoterpene ketones (0.97%), phenols (1.06%)	[19]
	Middle stage	Monoterpene esters (2.85%), monoterpene alcohols (76.77%), monoterpene aldehydes (0.01%), monoterpene ketones (3.43%), phenols (1.1%)	
	Final stage (mature fruits)	Monoterpene esters (0.90%), monoterpene alcohols (88.51%), monoterpene aldehydes (0.16%), monoterpene ketones (2.61%), phenols (2.31%)	

composition of *C. sativum* fruit EO has been represented in Figure 2.

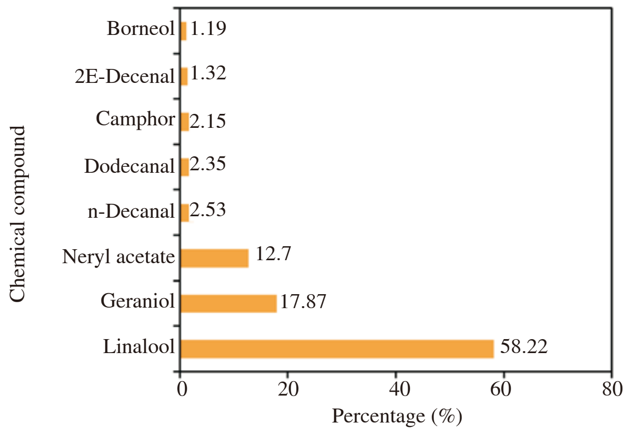

Figure 2. Chemical composition of *C. sativum* fruit essential oil (data adapted from Soares *et al.*, 2012)[35].

The EO content of *C. sativum* at the beginning of flowering (generative stage) was 0.29 mL/100 g, containing 61 compounds, with 46 identified ones that constituted 99.8% of all the components of the oil, while the *C. sativum* harvested in the vegetative stage contained 0.17 mL/100 g EO with 65 determined compounds representing 99.8% of the total compounds in the EO[20]; the chemical composition of herb EO of *C. sativum* harvested in two different stages (generative stage and vegetative stage) has been depicted in Figure 3.

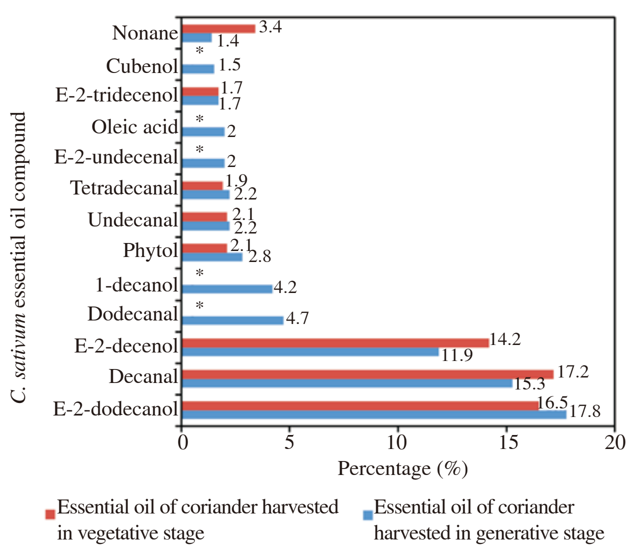

Figure 3. Compounds of essential oil of *C. sativum* harvested in two different stages (text data converted from Nurzynska-Wierdak, 2013 [20]).
*: Compounds not determined.

The compositions of *C. sativum* oils from different parts of the plant varied qualitatively and quantitatively. The *C. sativum* leaf EO (CLEO) contained 44 compounds mostly of aromatic acids containing 2-decenoic acid (30.8%), E-11-tetradecenoic acid (13.4%), capric acid (12.7%), undecyl alcohol (6.4%), tridecanoic acid (5.5%) and undecanoic acid (7.1%) as major constituents while the CLEO contains 53 compounds, linalool (37.7%), geranyl acetate (17.6%) and γ-terpinene (14.4%) being the major ones[1]. The major volatile compounds in CSEO, as has been reported by Shahwar *et al.*[25], were linalool, γ-terpinene, α-pinene, camphor, decanal geranyl acetate, limonene, geraniol, camphene and D-limonene, while the major identified volatile compounds in CLEO included (E)-2-decenal, linalool, (E)-2-dodecenal, (E)-2-tetradecenal, 2-decen-1-ol, (E)-2-undecenal, dodecanal, (E)-2-tridecenal, (E)-2-hexadecenal, pentadecenal and α-pinene. The aroma and flavour of coriander are due to EO present in oil glands in the mericarp, and the linalool that has floral and pleasant odour notes has been the major compound of the EO, the content variation of which in *C. sativum*, harvested in different parts of the globe, has been shown in Figure 4.

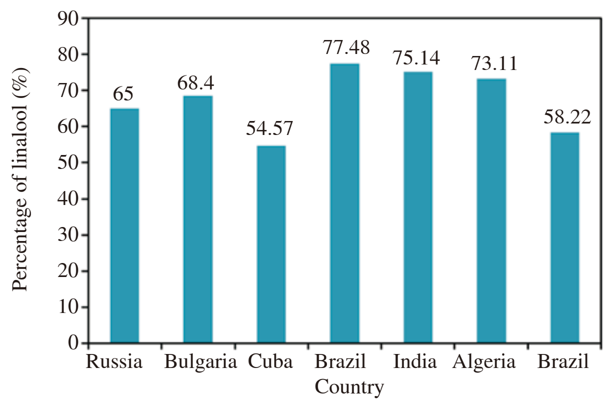

Figure 4. Linalool content of essential oil of *C. sativum* seed harvested in different country[5,35,53-57].

5. Antibacterial activity

Delaquis *et al.*[26] examined the antibacterial activity of crude oil and the distilled fractions coriander (seeds of *C. sativum* L.) and cilantro (leaves of immature *C. sativum*) against some Gram-positive and Gram-negative food spoilage bacteria (*Salmonella typhimurium*, *Listeria monocytogenes*, *Staphylococcus aureus* (*S. aureus*), *Serratia grimesii*, *Enterobacter agglomerans*, *Yersinia enterocolitica*, *Bacillus cereus*). The inhibitory effect of *C. sativum* on potential spoilage bacteria, such as *Klebsiella pneumoniae* (*K. pneumoniae*), *Bacillus megaterium*, *Pseudomonas aeruginosa* (*P. aeruginosa*), *S. aureus*, *Escherichia coli* (*E. coli*), *Escherichia cloaca*, *Enterococcus faecalis*, has been reported[27].

The *C. sativum* fruit EO (15 μL/disc) exhibited antibacterial effect against *E. coli*, *P. aeruginosa* and *Salmonella typhi* (*S. typhi*) showing zone diameter of inhibition 25, 10 and 18 mm, respectively[28]; at such levels, the modes of action of oils of *C. sativum* were demonstrated to be bactericidal against *S. typhi* and bacteriostatic action against *E. coli*. Linalool, the major component of the oil, which was reported to have antibacterial effect against many bacterial strains[29], could be responsible for antibacterial activity. As has been reported by Lalitha *et al.*[30], the concentration dependant antibacterial activity of the CSEO against potential food poisoning bacteria causing serious infection to humans was represented in Figure 5.

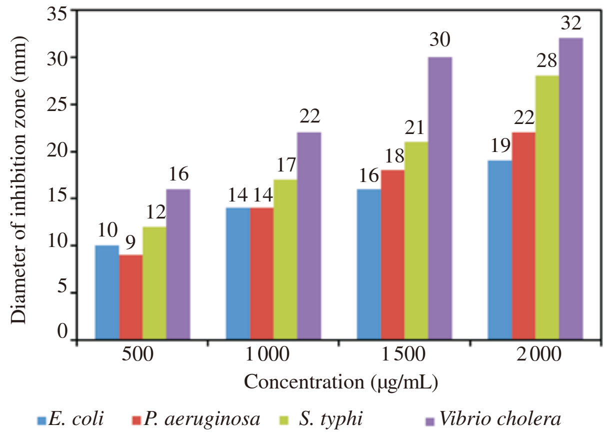

Figure 5. Antibacterial activity of CSEO (data table partly converted: Lalitha *et al*., 2011)[30].

Plantaricin *C. sativum*, an antimicrobial peptide containing 26 amino acids, isolated from coriander leaf extract exerted antimicrobial activities against Gram-negative bacteria showing minimum inhibitory concentration (MIC) values 71.55 and 86.4 μg/mL, respectively for *K. pneumoniae* and *P. aeruginosa* as well as Gram-positive (MIC 35.2 μg/mL for *S. aureus*) bacteria[31].

Nanasombat and Lohasupthawee[32] demonstrated the inhibitory effect of *C. sativum* EO against 25 bacterial strains (20 serotypes of *Salmonella* and 5 species of other enterobacteria: *Citrobacter freundii*, *Enterobacter aerogenes*, *E. coli*, *K. pneumoniae*, and *Serratia marcescens* showing MIC of 4.2 μL/mL to most bacterial strains; *Salmonella enterica* serotype *rissen* was resistant strains to *C. sativum* EO (> 62.5 μL/mL). Innocent *et al*.[33] evaluated the immunostimulant potential of *C. sativum* in fish *Catla catla*, post challenged with *Aeromonas hydrophila*, and thus, it has been found to be a good choice as diet supplement to induce disease resistance in fishes.

6. Antifungal activity

For *Candida* spp., MICs of CLEO ranged 15.6-31.2 μg/mL, and minimum fungicidal concentrations (MFCs) 31.2-62.5 μg/mL, while the active fraction had higher MIC and MFC values, ranging from 31.2 μg/mL to 250 μg/mL and 125 μg/mL to 1 000 μg/mL, respectively, indicating a synergistic activity of the EO components (mono- and sesquiterpene hydrocarbons) as their isolation into fractions led to a decreased antimicrobial effect, and hence *C. sativum* EO can be used as a potential candidate in the treatment of oral diseases, such as denture-related candidiasis[34]. The CSEO showed excellent antifungal activity against seed borne pathogens of paddy [*Pyricularia oryzae* (*P. oryzae*), *Bipolaris oryzae* (*B. oryzae*), *Alternaria alternata* (*A. alternata*), *Tricoconis padwickii* (*T. padwickii*), *Drechslera tetramera*, *Drechslera halodes* (*D. halodes*), *Curvularia lunata*, *Fusarium moniliforme*, *Fusarium oxysprorum* (*F. oxysprorum*)][30]: Figure 6 represents the concentration dependant killing activity of coriander oil for *P. oryzae*, *T. padwickii*, *B. oryzae*, *A. alternata*, *D. halodes* and *F. oxysporum*. Zare-Shehneh *et al*.[31] showed that the plantaricin *C. sativum*, from coriander leaf extract, had fungicidal activity against *Penicillium lilacinum* and *Asperjilus niger* with MICs 67.8 and 62.1 μg/mL, respectively.

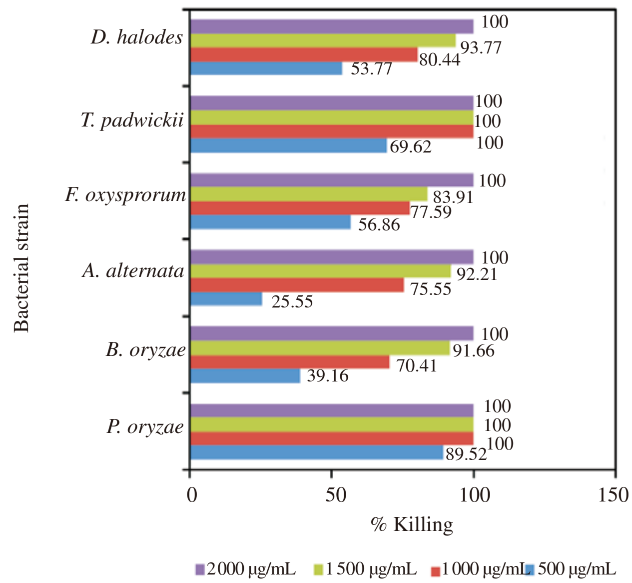

Figure 6. Fungicidal activity of CSEO (data table partly converted: Lalitha *et al*., 2011)[30].

As has been represented in Figure 7, the coriander EO induced diameter of inhibition zone of 20-32 mm at concentration 10 000 μg/mL against *Microsporum canis* (*M. canis*) strains, while for *Candida* strains, the growth inhibition zone induced by the oil was 9-10 mm, at concentration 10 000 μg/mL[35]. Figure 8 shows that the MICs for *M. canis* strains ranged 78-620 μg/mL and the MFCs ranged from 150 to 1 250 μg/mL, while the MICs for *Candida* spp. strains ranged 310-620 μg/mL and the MFCs 620-1 250 μg/mL[35].

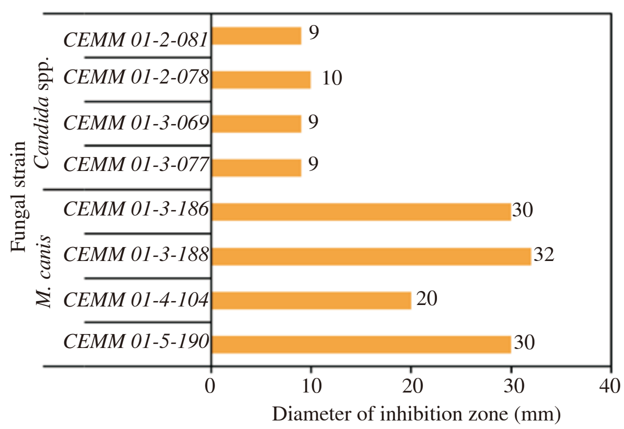

Figure 7. Diameter of inhibition zone of coriander essential oil against fungal starins (data adapted from Soares *et al*., 2012)[35].

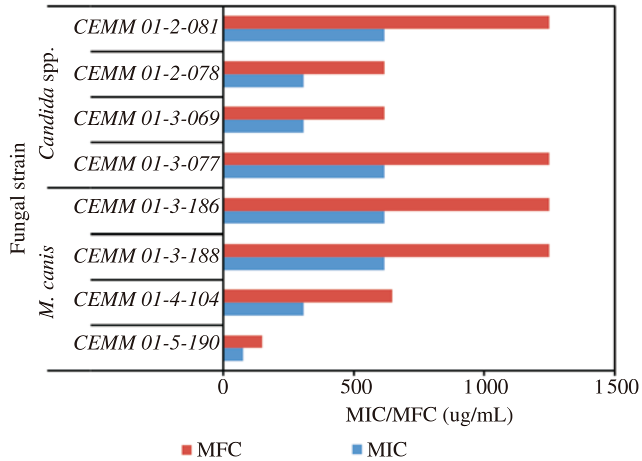

Figure 8. MIC and MFC of *C. sativum* essential oil against the fungal starins of *M. canis* and *Candida* spp (data adapted from Soares *et al*., 2012)[35].

7. Antioxidant activity

Antioxidants are used in the food industry to increase the shelf-life of the foods. Coriander, like many spices, contains antioxidants, which can delay or prevent the spoilage of food seasoned with this spice. Shahwar *et al*.[25] showed that the CSEO (500 µg) had significant radical scavenging activity (RSA; 66.48%) in comparison with CLEO (500 µg) having RSA of 56.73%, while the methanol extracts of both seed and leaves, at 500 µg/mL, showed RSA of 64.40% and 72.19%, respectively. Sriti *et al*.[21] reported that the methanolic extracts of coriander fruits showed better antioxidant activity than EOs, and the 2,2-diphenyl-1-picryl hydrazyl (DPPH) RSA scavenging ability of methanolic extracts of coriander fruits was higher than that of synthetic antioxidant butylated hydroxy toluene (BHT; IC_{50} = 25 µg/mL).

The microwave treated coriander seeds showed remarkable antioxidant activity against DPPH and β-carotene assays, due to the higher percentage of linalool in microwave heated coriander seeds (57.3%) than that in conventional roasted coriander seeds (55.5%), and also for the remarkable percentages of α-pinene, β-pinene, p-cymene and λ-terpinene which may be contribute to the antioxidant activities of the spice[23]. The CSEO and its fractions exhibited strong RSA, and hence can be used as a natural antioxidant in lipid-containing foods[36]. The extract and oil of leaves and seeds of coriander had strong antioxidant activity and thus, preventing the oxidative deterioration of food[37]. Anita *et al*.[38] determined the level of antioxidant in *C. sativum* seed (IC_{50}: 0.4 mg of the spice for DPPH free RSA) and analysed the seed extract for the presence of biomolecules having anti-oxidative activity. Wangensteen *et al*.[37], found that scavenging activity of CSEO is higher than CLEO; the antioxidant activity of CSEO was might be due to the presence of linalool in high concentration as compared to CLEO.

The antioxidant profile of *C. sativum* seed extract (mg/g dry weight), as per the report of Anita *et al*.[37], includes: oxidized ascorbate (0.15), reduced ascorbate (0.136), total ascorbate (0.287), riboflavin (0.0046), tocopherol (0.181), total polyphenol (18.7), gallic acid (0.173), caffeic acid (0.08), ellagic acid (0.162), quercetin (0.608), kaempferol (0.233). The *C. sativum* leaves are also rich in phytochemicals such as polyphenols, carotenoids and EO like linalool, which shows higher free RSA includes and ferric reducing antioxidant power. The *C. sativum* fresh leaf juice containing flavonoids (a major class of phenolic compounds with lower redox potential) had high antioxidant activities by its ability to scavenge hydroxyl- and superoxide-radicals, high reducing power, and protection against biological macromolecular oxidative damage and by increasing the level of glutathione[39].

8. Food preservation and anti-spoilage

The lipid peroxidation in food causes oxidative stress leading to the development of rancidity, unpleasant tastes and odors as well as changes in colour and losses of nutritional value[40]. The synthetic antioxidants *viz*., butylated hydroxyl anisole (BHA) and BHT have been in use in foods[41], but the safety of such synthetic antioxidants has been doubted due to their toxicity, liver damage and carcinogenicity[42]. The *C. sativum* possesses excellent antioxidant activity and it is stable at high temperatures and, thus can be used as the substitute for synthetic antioxidant. Having antibacterial, antifungal and anti-oxidative activities the *C. sativum* EO prevents spoilage of foods seasoned with the EO playing a great role in food preservation. Darughe *et al*.,[43] demonstrated that the *C. sativum* EO (0.05%-0.15%) inhibited the rate of primary and secondary oxidation product formation in cake, and their effects were almost equal to BHA (0.02%); after 30 days of storage, acidity of control and cake samples containing BHA (0.01% and 0.02%) was higher than in cakes containing different concentrations of coriander EO (0.05%-0.15%). The Italian processed food, salami, with coriander EO remained stable during the entire period of storage maintaining the peroxide value, and TBARS values compared to those of the products without antioxidant coriander EO presented stronger effect than that of BHT on the retardation of lipid oxidation, thus increasing the shelf life of the product[44].

9. Safety and toxicity

The estimated partial lethal dose (LD_{50}) in mice for *C. sativum* EO was tested 2 139.98 mg/kg indicating the low toxicity of the agent in accordance with Hedge and Sterner[45]. Freires *et al*.[34] demonstrated through pharmacogenomic analysis that the CLEO and its selected active fraction had low cytotoxicity on human cells. The CSEO (16 mg/plate) was tested negative for mutagenicity in the absence and presence of metabolic activation among the *Salmonella typhimurium* strains tested[9]. In the evaluation of plant extract toxicity by the brine shrimp bioassay, the partial lethal concentration (LC_{50}) value of < 1 000 µg/mL has been considered bioactive[46]; Soares *et al*.[35] demonstrated that the *C. sativum* fruit EO had LC_{50} value of 23 µg/mL. Patel *et al*. (2012)

[47] reported *C. sativum* extract as non-toxic, up to 3000 mg/kg body weight of mice, with normal haematological profile, and thus coriander can be considered as safe for consumption. However, there is strong need to evaluate and control the microbial quality of spices including and presence of microbial toxic metabolites[48].

10. Concluding remarks

The coriander, *C. sativum* L., plants provide two types of herbal raw materials-fruits and leaves, the main biologically active substance of which is EO, the composition of which may vary in different parts of the same plant. The EO and extracts of the plant possess promising antibacterial, antifungal and anti-oxidative activities in having various chemical components in different parts of the *C. sativum* plant. The *C. sativum* EO plays a great role in maintaining the shelf-life of foods by preventing their spoilage. This edible plant is non-toxic to humans, and the *C. sativum* EO is thus used in different ways, *viz*., in foods (like flavoring and preservatives) and in pharmaceutical products (therapeutic action) as well as in perfumes (flagrancies and lotions). The *C. sativum* EO and extracts can be used as natural antioxidants, in foods, as the substitute for widely used chemical and toxic antioxidants (butylated hydroxyl and anisolea BHT). The green foliage of Dhane, rich in vitamins and other minerals, is used in vegetables and salads while the seeds, containing EO rich in linalool, are used mainly as the component of spices and medicines. The varying composition of *C. sativum* EO and extract is the reason why the herb with young plants is used to prepare curry, soups and sauces, whereas the fruit is mainly used as a seasoning for pickles, cold meats, confectionery products, and seasoning mixtures. Based on the history of consumption of coriander oil without reported adverse effects, lack of the plant's toxicity in the scientific studies and of its major constituent, linalool, the use of coriander oil as an added food ingredient has been considered safe[4].

Conflict of interest statement

We declare that we have no conflict of interest.

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