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A Review of Phytochemistry and Antimicrobial Properties of Essential Oil from Coriander (*Coriandrum sativum* L., Apiaceae)

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Authors' contributions

This work was carried out in collaboration among all authors. Author ANBS wrote the original draft, curated the data, conducted formal analysis, and participated in review and editing. Author FLLA conceptualized the study, curated the data, developed the methodology, created visualizations, and participated in review and editing. Author AMN curated the data, developed the methodology, created visualizations, and participated in review and editing. Author ROSF acquired funding, administered the project, created visualizations, and participated in review and editing. All authors read and approved the final manuscript.

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ABSTRACT

Aim: The study is a systematic review of the literature with emphasis on the chemical and antimicrobial properties of *Coriandrum sativum* essential oil. Popularly known as coriander, the annual plant is an edible herb and cultivated all over the world, the plant-based compounds have been one of the alternatives in therapeutic and infectious disease treatments.

Methodology: An electronic search was performed using the PubMed/MEDLINE (Medical Literature Analysis and Retrieval System Online), Scopus and Web of Science databases. Articles were selected within the range from January 2014 to September 2024, which were within the theme of antibacterial, antifungal and phytochemical profile.

Results: Interesting results showed that the essential oil of *C. sativum* has an important antimicrobial activity against a range of microorganisms, including Gram-negative and Gram-positive bacteria, yeasts and filamentous fungi of clinical importance, proving to be a biological product with potential for the pharmaceutical industry in the advancement of new antifungals and the control of microbial resistance. The fruits and seeds of *C. sativum* have a similar chemical composition, predominantly comprising oxygenated monoterpenes, whereas the leaves contain saturated fatty aldehydes and alcohols as major compounds.

Conclusion: In conclusion, the essential oils of various parts of C. sativum, as well as their constituents, can be considered as treatments for infectious diseases caused by bacteria and fungi of great clinical importance. However, further studies should explore the mechanisms of activity and cytotoxic effects.

Keywords: Bacteria; filamentous fungi; yeasts; antimicrobial drugs; phytochemical profile.

1. INTRODUCTION

Plants are living chemical factories for the biosynthesis of a huge variety of secondary metabolites. In fact, it is these metabolites that form the basis for many pharmaceutical drugs and herbal medicines (Li, et al., 2020). Since ancient times, humans have used these metabolites in various areas, including medicine, the cosmetics industry and gastronomy. The traditional use of medicinal plants in the treatment of diseases is a practice cultivated to the present day. It is estimated that, currently, more than 80% of the global population relies on traditional herbal medicines for disease treatment and primary health care (Swamy et al., 2016; Saygia et al., 2021).

Among the families of the plant kingdom of great importance, Apiaceae (Umbelliferae) stands out, which covers about 446 genera of 3,540 herbaceous species, including *C. sativum* (Trifan et al., 2021). This arose from the Mediterranean area; however, it has become widely cultivated in Central Europe and North Africa, developing best in tropical and subtropical climates. It is also found growing in a variety of habitats, including gardens and open spaces (Laribi et al., 2015).

Antimicrobial resistance (AMR) is a threat to global health, requiring urgency due to its great social and economic impact. The World Health Organization reported that in 2019 resistant bacterial infections caused around 1.27 million deaths worldwide, in addition, fungal infections and neglected emerging diseases are responsible for 1.7 million deaths worldwide annually (De Souza et al., 2020).

In efforts to mitigate the health impacts of AMR, scientific research is increasingly focused on medicinal plants, which contain numerous bioactive compounds with potential therapeutic applications. This systematic review aims to elucidate the chemical and antimicrobial properties of *Coriandrum sativum* essential oil.

2. MATERIALS AND METHODS

The research is a systematic review of the literature on the microbial activities and phytochemical profile of *C. sativum* essential oil. Articles on this topic were selected between January 2014 and September 2024. The searches were carried out in PubMed/MEDLINE (Medical Literature Analysis and Retrieval System Online), Scopus and Web of Science. The research descriptors were chosen according to the Descriptors in Medical Subject Headings (MeSH). Systematic search strategies were built by means of advanced searches according to each database, combined with Boolean operators AND and OR. The descriptors used were "Chemical compounds"; "Phytochemistry";

"Essential oil", "*Coriandrum sativum*"; "Antibacterial; " Antifungal", "Antibiofilm", "Nanoparticle" and "Nanoemulsion". The inclusion criteria consisted of articles published in English, studies published from January 2016 to December 2021. The exlusion criteria consisted of articles with antimicrobial activity of *C. sativum* oil, but not having information with part of the oil from which the plant was extracted and extraction method, articles not published in English language and studies published before January 2014.

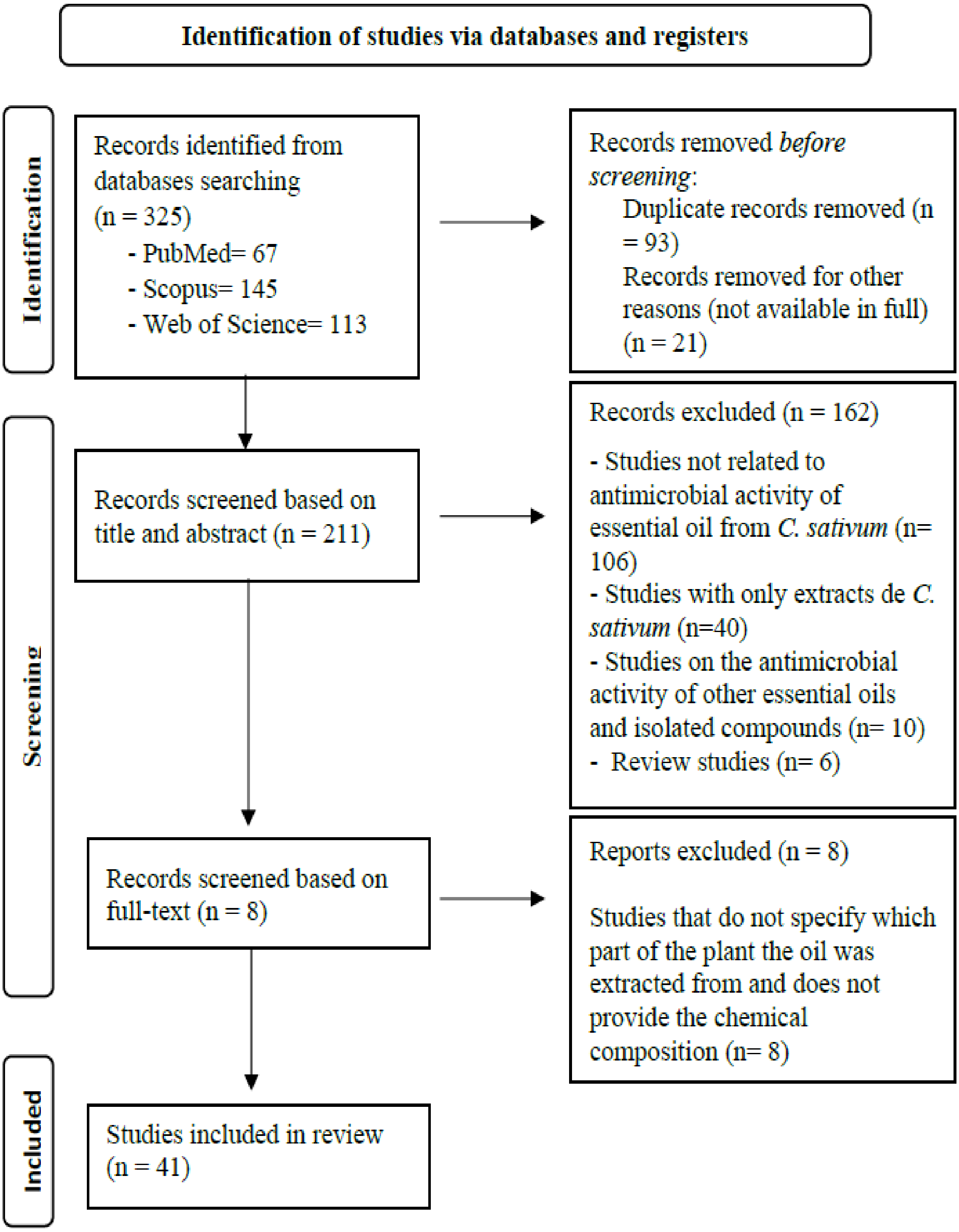

Fig. 1. PRISMA flow diagram

The PRISMA flow diagram showing the study selection processes is provided in Fig. 1. Data were extracted and exported into a standardised data extraction table in Microsoft Excel. The following data were extracted from the selected studies: Anatomical parts from which the oil was extracted, extraction method, composition analysis method and the five most present compounds in the oil. In the biological analysis, the microorganisms analyzed were extracted, as well as the MICs for each of the microorganisms. In the biofilm studies, the inhibition percentages were extracted. From the studies with nanoparticles including the gel, data on the composition of the nanoparticles were extracted, in addition to the microorganisms tested.

3. RESULTS AND DISCUSSION

3.1 *Coriandrum sativum* L.

Coriandrum sativum, belonging to the family Apiaceae (Umbelliferae), popularly known as coriander, is a species originating in the Mediterranean and the Middle East, widely recognized for its uses in cooking and traditional medicine worldwide (Scazzocchio et al., 2017; Mansouri et al., 2018). The plant is highly adaptable to soil and climate conditions, being cultivated mainly in regions with the warm climates such as the north and northeast of the country (Trifan et al., 2021).

Coriander is an erect annual herb with pronounced root, with slender, branching stems ranging from 20 to 70 cm in height. Its leaves are green or dark green, lanceolate, glabrous on both surfaces, lobed and with varied shapes (Saha et al., 2018). The flowers are small, pink or white, asymmetrical, with distributed petals pointing away from the umbel and towards its center (Tariq and Sadiq, 2015). Its fruit is a globular schizocarp, with 3 to 5 mm diameter and highly appreciated in cooking, while its seeds are dried schizocarps with two mericarps containing oval globules. In addition, the stems of *C. sativum* are light green with hollow branches and a glabrous surface (Sahu et al., 2018).

Ethnobotanical research involving *C. sativum* has addressed its magnificent effects on traditional medicine since antiquity around the world. Its seeds were consumed to relieve pain, rheumatoid arthritis, and inflammation, while the decoction of coriander was believed to treat mouth ulcers and redness in the eyes. In addition, the coriander has been prescribed to relieve gastrointestinal disorders such as flatulence and diarrhea and indigestion, and it's also used to treat diabetes and a variety of conditions in the urinary, skin, cardiovascular, respiratory and neurological systems (Talebi et al., 2024). It has been reported that coriander exhibits a broad spectrum of therapeutic effects including insecticidal, antioxidant, antimutagenic, sedative hypnotic, antihelmintic, anticonvulsant, diuretic, antifungal, antimicrobial, anxiolytic, anticancer, anti-aging, hepatoprotective properties (Hajlaoui et al., 2021).

Both coriander essential oil and extracts are interesting sources of bioactive compounds and are widely used as spices in culinary practice due to their unique aroma and taste (Kaˇcániová et al., 2020). Furthermore, due to its allelopathic properties, *C. sativum* essential oil can be exploited as a biological agent in pest and weed management in agriculture, causing less environmental damage, as well as widespread public acceptance, with activity against phytopathogens such as *Fusarium graminearum*, as well as no bioherbicidal potential against seed germination of *Amaranthus retroflexus* plants, *Chenopodium album* and *Echinochloa crus-galli* (Sumalan et al., 2019).

3.2 Chemistry Composition of Essential Oil from *C. sativum*

Coriander contains a wide range of phytochemicals, including essential oils, which can be extracted from various parts of this plant material such as leaves, stems, flowers, fruits, seeds and roots. Essential oils are a mixture of volatile compounds from the secondary metabolism of plants, with great therapeutic value due to the different biological activities resulting from the major compounds or the synergy between the complex mixture of their constituents (Bunse et al., 2022).

The chemical composition of the essential oil varies not only according to the different botanical species, but also according to the parts of the plants used, time of harvest, environmental conditions and genetic factors (Kumar et al., 2022; Talebi et al., 2024). Generally, the constituents of essential oil of *C. sativum* are a complex mixture composed mainly oxygenated monoterpenes, saturated fatty aldehydes, monoterpenes hydrocarbons, alkanes and alcohois (Fig. 2).

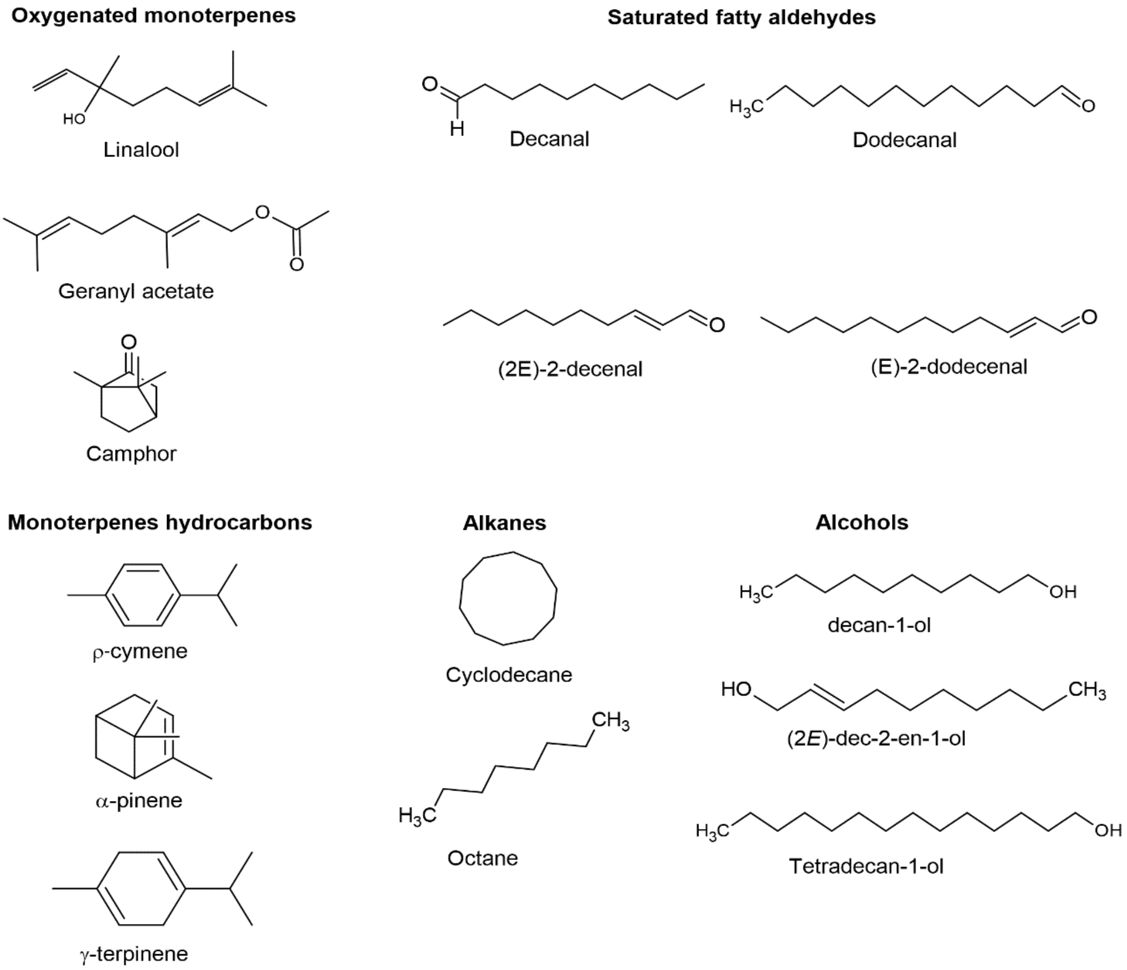

Fig. 2. Structures of the major compounds

Other factors that influence the composition are the extraction methods used. Hydrodistillation is the most effective and widely used technique for the extraction of *C. sativum* essential oil. However, other methods are described as steam distillation, microwave-assisted hydrodistillation, and fluid supercritical extraction. Table 1 summarizes the main chemical constituents found in the aerial parts (stem, leaves and fruits), fruits, leaves, seeds and stem with leaves of *C. sativum*. In addition, it describes the methods of extraction and analysis of the constituents and the country where the plant specimen was collected.

Linalool (2,6-dimethyl-2,7-octadien-6-ol) (Fig. 2) is a monoterpene compound that is the main constituent present in the essential oil of coriander fruits and seeds, depending on the geographic region and can vary from 70 to 90% (Table 1) of the chemical constitution. Other components such as α-pinene and γ-terpineol are also well represented in the fruit and seed composition of *C. sativum*.

The structural part of the leaves is where the greatest variation of the chemical compounds occurs, individually as well as in the final disposition. In the shoot, linalool, for example, when present, often represents less than 1% of the oil's constitution. However, depending on climatic conditions and geographical location, planting and gathering it is possible for it to be extracted in higher quantities. In a study to compare two methods of extracting oil from the leaves of *C. sativum,* collected in Pakistan, linalool was observed as the compound responsible for more than 50% of the oil constitution (Abbas et al., 2021). In a study conducted in China, linalool was the second most present compound, corresponding to 21.61% of the chemical composition (Yildiz et al., 2016).

The major compounds usually present in coriander leaves are fatty aldehydes, such as decanal, decenal, dodecanal, and dodecenal, as well as alcohols such as decanol, decenol, and tetradecanol. A study described by Amiripour et al. (2021) showed the effect of salinity on fatty aldehydes. In the treatments in which the plant suffered greater salt stress, the oil showed an increase in saturated acids and the major compound 2-E-decanal, while in lower salinity, the amount of η-decanal decreased.

3.3 Antibacterial Activity

The essential oil activity of several parts of *C. sativum* is described against a number of Gram-negative bacteria, including species of the family Enterobacteriaceae, *Pseudomonas aeruginosa, Bacillus subtilis, Pasteurella multocida, and Vibrio* spp. In Gram-positive, the oil has activity against *Staphylococcus* spp., *Enterococcus* spp., *Listeria* spp., and *Micrococcus luteus* (Hajlaoui et al., 2021; Foudah et al., 2021; Abbas et al., 2022). In addition to activity against a range of oral pathogens such as *Fusobacterium nucleatum, Porphyromonas gingivalis, Streptococcus mitis* and *Streptococcus sanguinis* (Bersan et al., 2014).

The antimicrobial activity of the essential oil, in addition to its chemical composition, also depends on the characteristics of the microorganism. Gram-negative bacteria are more resistant than Gram-positive bacteria due to their distinct characteristic of having a membrane outside the cell wall (Breijyeh et al., 2020). The Minimum Inhibitory Concentrations (MICs) of coriander essential oil, depending on the anatomical structure, can vary from <0.195 to 1,875 μg/mL for Gram-negative and from <0.195 to 469 μg/mL for Gram-positive (Table 2). A MIC of 1,875 μg/mL was found for seed EOCS against *P. aeruginosa* ATCC 27853 (Hajlaoui et al., 2021). However, in other studies, the MICs for coriander seed oil against *P. aeruginosa* (ATCC 9027) and *P. aeruginosa* (isolated from food) were much lower, with values of 3.0 and 0.39 μg/mL, respectively, while leaf oil showed a MIC of 6.25 μg/mL against the *P. aeruginosa* strain ATCC 9027. Although Gram-negative strains are more resistant, the essential oil of *C. sativum* showed greater activity against these microorganisms than against Gram-positive bacteria *B. cereus, S. epidermidis and L. monocytogenes.*

In the studies analyzed, most of the microorganisms tested were of reference strains of the American Type Culture Collection (ATCC) and the Leibniz institute DSMZ-German collection of microorganisms and cell cultures GmbH, with only one study testing against pathogens isolated from food and only one record of activity against multidrug-resistant clinical isolate, in which a strain of methicillin-resistant *Staphylococcus aureus* (MRSA) showed sensitivity to *C. sativum* seed essential oil with MIC of 8μg/mL, similar to the MIC presented against the *S. aureus* strain ATCC 25923, MIC 9 μg/mL (Eid et al., 2021).

Most of the studies also present the minimum bactericidal concentration (MBC) for EOCS. Based on CLSI (2006), MIC and MBC ratios of less than or equal to show that the compound is bactericidal and, therefore, it is possible to obtain safe concentrations of the compound that kill 99.9% of pathogens exposed to the antimicrobial. The oil showed bactericidal concentrations for most of the pathogens tested.

3.4 Antifungal Activity

Similar to studies with antibacterial activity, few data are found on the antifungal activity of *C. sativum* essential oil, with less than ten studies carried out in the last 10 years (Table 2). These studies focus mainly against yeast species of the genus *Candida.* This genus has several species responsible for invasive fungal infections (IFIs), with two species, *C. albicans* and *C. tropicalis,* included in the World Health Organization's list of fungal pathogens of critical importance. This list is based on the high risk of mortality or morbidity and seeks to guide research, development, and public health actions against IFIs caused by these pathogens (Fisher and Denning, 2023).

In studies with filamentous fungi, the essential oil shows activity against species of *Trichophyton* spp. and *Aspergillus* spp. (Table 1). The strains of *Aspergillus* spp. were more sensitive than the dermatophytes *T. rubrum* and *T. mentagrophytes*. Only in one of the six studies was the synergistic action of the oil with a standard antifungal analyzed, in which the oil of the fruit of *C. sativum* showed a synergistic effect associated with terbinafine against strains of *Trichophyton rubrum* and *T. mentagrophytes* (Trifan et al., 2021). The similarity of fungal cells and human cells means that most available antifungals exhibit cytotoxic effects. Therefore, modulatory activity studies with conventional drugs and natural products are an important strategy to decrease the effective concentrations of drugs and, consequently, reduce the side effects associated with their use.

All the strains used in the studies with yeasts and *Trychophyton* spp. were reference, such as the ATCCs and strains of the Central Bureau voor Schimmelcultures (CBS), and there were no reports of the antifungal activity of the oil against resistant strains. The mechanisms of action by which the oil acts on fungal cells are not fully understood. Only one of the studies analyzes the mechanism of action when evaluating the effects of the oil on the cell wall and ergosterol (Freires et al., 2014), in which the oil bound to free ergosterol demonstrating an affinity for this compound, a mechanism similar to that presented by the drug Amphotericin B. In addition, all studies focus on *in vitro* activity and not *in vivo* models. These questions open up new avenues of investigation for scientists to explore to advance the search for new antifungal agents.

3.5 Antibiofilm Activity

Microbial biofilms are aggregates of microorganisms surrounded by an extracellular polymeric matrix, which confers resistance to antimicrobial agents. The antibiofilm effect has been specifically reported with the oil extracted from the leaves and stems of *C. sativum.* The effect of EOCS on the inhibition of biofilm adhesion showed that the EOCS substantially affected the structure of the biofilm, causing cells to transition from turgid to withered, similar to observations with nystatin (used as a positive control) (Freires et al., 2014). EOCS exhibited non-adherent activity (42–85%) at low concentrations against all tested strains, with particularly notable results against *Candida tropicalis*, where a concentration of 7.81 µg/ml inhibited biofilm adhesion by 84.63% (Freires et al., 2014).

Confocal scanning analysis by Freire et al. (2015) revealed that EOCS substantially reduced the metabolic activity of *Candida albicans* biofilms. EOCS is believed to bind to ergosterol in the fungal cell membrane, increasing membrane permeability and leading to cell death, a mechanism similar to polyene antifungals. Major compounds in coriander such a linalool and trans-2-decenal exhibit potent fungicidal effects, causing fungal cell lysis (Freires et al., 2014).

Abbas et al. (2022) demonstrated that EOCS exhibited antibiofilm activity against *Escherichia coli* and *S. aureus* with percentages of 64.75% and 52.92%, respectively. Barbosa et al. (2023) investigated the dose-dependent antibiofilm activity of EOCS (10-70%) against various concentrations (20 mg/mL to 80 mg/mL), showing significant differences ($p \leq 0.05$). Low concentrations of EOCS have been shown to inhibit *C. albicans*, attributed to its terpene-rich chemical composition (Barbosa et al., 2023 and Freire et al., 2014).

3.6 Nanoparticles of *Coriandrum sativum* L. Enhance the Antimicrobial Effect

Nanotechnology is an interdisciplinary field focused on the development and application materials at the nanoscale. In the pharmaceutical industry, nanotechnology plays a crucial role in targeted drug delivery and enhancing drug bioavailability (Ashraf et al., 2019; Wilson et al., 2022). Metal nanoparticles developed from *C. sativum* extracts have demonstrated significant antimicrobial activity, particularly against strains of *E. coli* and *S. aureus* (Ashraf et al., 2019; Eid et al., 2022; Asmat-Campos et al., 2024).

Another drug delivery system, nanoemulsions, are colloidal systems with particle sizes ranging from 10 to 1,000 nm (Jaiswal et al., 2014), consisting of a mixture of oil, water, and surfactant. Given their importance in drug delivery and the antimicrobial properties of *C. sativum* oil, two studies have explored the encapsulation of this oil in nanoemulsions and its antimicrobial effects. The action of nanoemulgel with EOCS was described in a study by Eid et al. (2021), whose effects on *K. pneumoniae, P. aeruginosa*, and MRSA were greater than the antibiotics ampicillin and ciprofloxacin, with MIC of 5 µg/ml, 3 µg/ml, and 8 µg/ml, respectively. Additionally, chitosan-based nanoemulsions incorporating EOCS showed antifungal effect against filamentous fungal species of the genera *Aspergillus, Penicillium, Fusarium* and species of *Mycelia sterilia* and *Cladosporium herbarum* (Das et al., 2019).

Nanoemulsions incorporating linalool have also been developed to enhance the antibacterial properties of this compound using different types of co-emulsifiers (Table 3). These nanoemulsions demonstrated antimicrobial activity against foodborne pathogens by reducing MIC concentrations compared to free linalool.

Table 1. Geographical location, extraction method, identification and major constituents of the essential oil from various parts of *Coriandrum sativum* L.

Parts	Geographic location	Majoritary compounds	%	Extraction method	Identification method	Reference
Aerial parts	Algeria (Djelfa)	Linalool Eugenol Aceteugenol γ-Terpinene α-Pinene	60.91 8.95 6.70 3.25 2.52	Hydrodistillation	Hewlett Packard Agilent 6890 GC equipped with an HP-5MS capillary column	Mansouri et al. (2018)
Fruits	India	Linalool γ-Terpinene Tetradecanoic acid ethyl ester α-Pinene Dodecenal	66.29 5.26 4.56 3.46 2.12	Hydrodistillation	Shimadzu 15A GC using a flame ionisation detector (FID).	Sourmaghi et al. (2015)
		Linalool Geranyl acetate Dodecenal Tetradecanoic acid	63.27 8.49 2.90 2.89	Microwave-assisted hydrodistillation		
	Portugal	Linalool γ-Terpinene Geranyl acetate α-Pinene 2-*trans*-Decenal	59.6-72.6 8.1-12 1.7-4.5 1.7-4.3 1.4 – 3.3	Hydrodistillation	GC-FID instrument-PerkinElmer Clarus 400 GC	Machado et al. (2023)
	Romania	Linalool α-Pinene γ-Terpinene Camphor Geranyl acetate	67.87 8.13 5.77 3.82 3.71	Hydrodistillation	Sistema GC/Finnigan Focus	Trifan et al. (2021)
	Romania (Transylvania)	Linalool Camphor *ρ-cymene* α-Pinene cis-linalool oxide	73 6.7 6.02 4.57 1.88	Hydrodistillation	Trace DSQ Thermo Finnigan quadrupole mass spectrometer coupled with a Trace GC.	Miclea et al. (2019)

Parts	Geographic location	Majoritary compounds	%	Extraction method	Identification method	Reference
	Slovakia	Linalool Camphor Geranyl acetate Cymene D-limonene	66.07 8.34 6.91 6.35 2.93	Water vapor distillation	GC-MS Agilent 7890 B, Agilemt 5977A	Kačániová et al. (2020)
Leaves	Brasil	Decanal 2E-decenal 2-decen-1-ol Ciclodecane Cis-2-dodecenal	19.09 17.54 12.33 12.15 10.72	Hydrodistil lation	GC- Hewlett-Packard 6890 / HP-5975	Freires et al. (2014)
		5-methyl-2-(1-methylethyl)-phenol Octane Decanal Tetradec-2-enal <trans> *E* -tridecen-1-al	14.87 8.85 8.21 7.70 6.75	Hydrodistillati on	Shimadzu GC-MS- QP5050A	Barbosa et al. (2023)
		Linalool *Linalool oxide* *ρ-cymene* *Camphor* *α-pinene*	39.78 27.33 17.62 7.45 4.95	Steam distillation	Shimadzu GC-MS GC17-A	Sousa et al. (2016)
	Ethiopia (Jimma)	Hexanedioicacid,bis(2-ethylhexyl) ester 2E-decenal *Linalool* *1-Decanol* 2E – dodecenal	46.89 12.60 8.32 6.11 4.53	Hydrodistillatio n	(GC) 7890 (Agilent Technologies Palo Alto, CA, USA) fitted MS detector (Agilent 5977 AMS) and DB-5MS fused silica capillary columns	Atnafu et al. (2024)
	Iran (Kermanshah)	*n* -Hexadecane Tetrahydroionol 2E – dodecanal Neryl acetate	29.23 28.00 25.06 23.86	Distillation of dried leaves into powder form (dissolved in ethanol)	GC-MS (Thermo	Zangeneh et al., (2018)

Parts	Geographic location	Majoritary compounds	%	Extraction method	Identification method	Reference
		Carvacrol	21.55		Quest Finningan, UK)	
	Saudi Arabia	1-decanol Decanal Trans-2-Dodecen-1-ol Menthone trans-2-Decen-1-ol	17.85 11.04 7.87 6.71 5.44	Hydrodistillation	Agilent 7890B GC and Agilent 5977B MSD	Foudah et al. (2021)
	China	(E)-2-decenal Linalool (E)-2-dodecenal Dodecanal (E)-2-undecena	29.87 21.61 7.03 5.78 3.84	Hydrodistillation	(GC-MS) Agilent-7890B/ Agilent 5975C	Yildiz (2016)
Seeds	Brazil	Linalool 2-dodecanal Palmitic acid Geraniol 2-decenal	64.4 5.5 5.3 5.1 3.6	Hydrodistillation	GCMS-QP2010 ULTRA (Shimadzu)	Dos Santos et al. (2019)
	India (Jaipur)	Linalool Geranyl acetate α-pinene Estragole *trans*-Anethole	76.74 6.51 5.65 1.63 1.21	Hydrodistillation	Shimadzu GC-2010. Carrier gas, Nitrogen was used at 10 psi inlet pressure with FID and Omega SPTm column	Jain et al. (2023)
	Italy (Roma)	Linalool α-pinene *p*-Cymene Camphor Limonene	69.6 9.9 4.9 4.0 2.5	obtained from a commercial source	GC/MS, using an Agilent Technologies 6850 GC coupled with an Agilent Technologies 5975 MS	Scazzocchio et al. (2017)
	Iran	Linalool γ-terpinene Geranyl acetate α-pinene octanol	56.79 9.80 7.75 7.67 3.02	Hydrodistillation	Agilent 6890/5975 GC-MS System, equipped with a HP-	Bazargani and Rohloff (2016)

Parts	Geographic location	Majoritary compounds	%	Extraction method	Identification method	Reference
					5MS capillary column	
	Iran (Dezful)	Linalool α-pinene γ-terpinene Geranyl acetate o-Cymene	74.15 9.42 7.09 2.99 2.2	Hydrodistillation	GC-FID analysis on a ThermoQuest-Finnigan apparatus	Talebi et al., 2024
	Iran (Mashhad)	Linalool Octane Decane α-pinene Dodecane	52.6 10.3 7.3 5.9 2.7	Microwave-assisted hydrodistillation	Gas chromatography-mass spectrometer (Konik, HRGC 5000c, Spain) with quadrature detector and DB-5 capillary column	Ghazanfari et al. (2020)
	Iraq (Baghdad)	Linalool α-pinene γ-terpinene Geranyl acetate o-Cymene	74.14 8.31 6.27 2.36 1.7	Hydrodistillation	GC-FID analysis on a ThermoQuest-Finnigan apparatus	Talebi et al., 2024
	Romania (Neamt County)	Linalool α-pinene D-Limonene *p*-Cymene Camphor	45.38 11.62 9.62 8.00 6.01	Steam distillation	(GC-MS) Shimadzu QP 2010Plus	Sumalan et al. (2019)
	Romania	Linalool α-pinene myrcene γ-terpinene camphor	70.20 6.17 5.39 4.81 3.23	Supercritical CO2	GC by means of a GC Varian (Santa Clara, California, US) 450 provided with autosampler, split/splitless (S/SL) injector and flame ionization detector	Dima et al. (2014)
	Tunisia	Linalool γ-terpinene	76.41 5.35	Hydrodistillation	GC-MS, using a Hewlett-Packard	Hajlaoui et al. (2021)

Parts	Geographic location	Majoritary compounds	%	Extraction method	Identification method	Reference
		α-pinene Camphor Geranyl acetate	4.44 2.20 1.81		5890 series II CG	
	Tunisia (Korba)	Linalool Carvacrol γ-terpinene Camphor α-pinene	72.34 6.41 5.67 3.04 2.47	water-steam distillation	(GC–MS) analysis on Agilent 7890 gas chromatograph, equipped, coupled to an Agilent 5975C mass spectrometer with electron impact ionization (70 eV) and equipped with a flame-ionisation detector (FID)	Lasram et al. (2019)
	Turkey	Linalool cis-ocimene Neryl Acetate γ-terpinene	69.4 6.05 5.71 4.34	Hydrodistillation	GCMS QP 2010 Ultra (Shimadzu)	Özkinali et al. (2021)
		Linalool Camphor γ-terpinene α-pinene Geranyl acetate	79.12 6.16 2.82 2.67 2.10	Hydrodistillation	GC-MS using Trace 1310 gas chromatograph equipped with an ISQ single quadrupole mass spectrometer (Thermo Fischer Scientific, Austin, TX)	
	Turkey (Isparta)	Linalool 3-Hexyl hydroperoxide	98.9 1.04	Hydrodistillation	GC–MS analysis. GC–MS and GC-FID using a Shimadzu 2010 Plus with QP-5050 quadrupole detector equipped with a RxiR-5Sil MS (30 m × 0.25 mm, 0.25 μm) capillary	Önder et al. (2024)

Parts	Geographic location	Majoritary compounds	%	Extraction method	Identification method	Reference
					column and CP-Wax 52 CB (50 m × 0.32 mm; film thickness 0.25 μm), respectively.	
Stem and leaves	Tajikistan	(2E)-dodecenal Decanol Decanal Tetradecanol (2E)-deceno-1- ol	16.5 14.9 11.3 9.2 7.39	Hydrodistil lation	Shimadzu GCMS-QP2010	Sharopov et al. (2017)
	Pakistan	Linalool α-pinene Camphor Geranyl acetate γ-terpinene	61.78 8.89 7.16 5.87 3.95	Hydrodistil lation	Sistema GC/Finnigan Focus	Abbas et al. (2022)
		Linalool Phytol α-pinene Methyl Geranyl acetate	51.34 12.71 9.91 6.19 4.23	Supercritic al Fluid Extraction		

Table 2. Antimicrobial and antibiofilm activities of *C. sativum* essential oil

Activity biological	Microorganism (Gram)	MIC µg/mL	Part of the Plant	References
Antibacterial	*Escherichia coli* (-)	0.78	Fruits	Sourmaghi et al. (2015)
	Pseudomonas aeruginosa (-)	6.25		
	Staphylococcus aureus (+)	3.12		
	Bacillus cereus (+)	117	Seeds	Hajlaoui et al. (2021); Özkinali et al. (2017); Eid et al. (2021).
	Enterobacter aerogenes (-)	3.12		
	Enterococcus durans (+)	100		
	Enterococcus faecalis (+)	59 1.56		
	Enterococcus faecium (+)	<0.195		
	Escherichia coli (-)	469 50 5.5		
	Klebsiella pneumoniae (-)	0.390 5		
	Listeria innocua (+)	0.390		
	Listeria monocytogenes (+)	469		
	Micrococcus luteus (+)	59		
	Pseudomonas aeruginosa (-)	1,875 0,3903		
	Proteus vulgaris	8		
	Salmonella enteritidis (-)	<0.195		
	Salmonella kentucky (-)	<0.195		
	Salmonella typhimurium (-)	<0.195		
	Staphylococcus aureus (+)	117 12.5 9		
	S. aureus- MRSA (+)	8		
	Staphylococcus epidermidis (+)	117		
	Vibrio parahaemolyticus (-)	938		
	Vibrio alginolyticus (-)	234		
	Vibrio furnisii (-)	469		

Activity biological	**Microorganism (Gram)**	**MIC µg/mL**	**Part of the Plant**	**References**
	Vibrio mimicus (-)	938		
	Vibrio natrigens (-)	1.875		
	Vibrio carhiaccae (-)	938		
	Vibrio fluvialis (-)	469		
	Bacillus subtilis (-)	125	Leaves	Foudah et al. (2021) Bersan et al. (2014)
	Fusobacterium nucleatum (-)	15		
	Klebsiella pneumoniae (-)	125		
	Porphyromonas gingivalis (-)	125		
	Staphylococcus aureus (+)	500		
	Streptococcus mitis (+)	63		
	Streptococcus sanguinis (+)	250		
	Staphylococcus aureus (+)	129	Stem and leaves	Abbas et al. (2022)
	Bacillus subtilis (-)	103		
	Escherichia coli (-)	72		
	Pasteurella multocida (-)	86		
Antifungal	*Candida albicans*	31,25 250	Leaves	Barbosa et al. (2023)
	C. dubliniensis	31.25		
	Candida glabrata	62.5		
	Candida guilliermondii	125		
	Candida krusei	31.25 125		
	C.rugosa	15.6		
	C. tropicalis	31.25 250		Freires et al. (2014)
	Candida utilis	31.25		
	C. albicans	59	Seeds	Hajlaoui et al. (2021)
	C. glabrata	59		
	C. krusei	59		
	C. parapsilosis	59		
	S. cerevisae	29		
	T. rubrum	*512*	Fruits	Trifan et al. (2021)
	T. mentagrophytes	*512*		

Activity biological	**Microorganism (Gram)**	**MIC µg/mL**	**Part of the Plant**	**References**
	Aspergillus flavus	*102*	Stem and leaves	Abbas et al. (2022)
	A. niger	*74*		
	A. alternata	*92*		
Antibiofilm	*C. albicans*			Freire et al. (2015)
	S.mutans	Leaves		
	C. albicans			Freire et al. (2014)
	C. dubliniensis			
	C. krusei	Leaves		
	C. tropicalis			
	C.rugosa			
	Candida spp.	Leaves		Barbosa et al. (2023)
	Candida albicans	Leaves		Bersan et al. (2014)
	Streptococcus sanguinis			
	Streptococcus mitis			
	Porphyromonas gingivalis			
	Fusobacterium nucleatum			
	Esherichia coli			Abbas et al. (2022)
	Staphylococcus aureus	Stem and leaves		

Table 3. Nanoparticles of *Coriandrum sativum* L. with antimicrobial activity

Nanoparticle	Composition	Microorganism	Reference
Nanoemulgel	Seeds Essential Oil, Carbopol 940, Tween 80, span 80	*S. aureus* MRSA *Escherichia coli* *Proteus vulgaris* *Klebsiella pneumoniae* *Pseudomonas aeruginosa* *Candida albicans*	Eid et al., 2021
Nanoemulsion	Essential Leaves Oil, Chitosan Solution, Tween 80, Dichloromethane, Sodium Tripolyphosphate	*Aspergillus flavus* *Aspergillus niger* *Aspergillus fumigatus* *Aspergillus sydowii* *Aspergillus repens* *Aspergillus versicolor* *Aspergillus luchuensis* *Alternaria alternata Penicillium italicum* *Penicillium chrysogenum* *Penicillium spinulosum* *Mycelia sterilia Cladosporium herbarum* *Fusarium poae* *Fusariaum oxysporum*	Das et al., 2019
Nanoemulsion	Linalool 5% and tween 80 33.3%	*Salmonella typhimurium*	Prakash et al., 2019
Nanoemulsion	Linalol 4% e lectina 2%	*Salmonella typhi* *Escherichia coli O157:H7* *Staphylococcus aureus Listeria monocytogenes*	Taghavi et al., 2021

4. CONCLUSIONS

The fruits and seeds of *C. sativum* have a similar chemical composition, predominantly comprising oxygenated monoterpenes, whereas the leaves contain saturated fatty aldehydes and alcohols as major compounds. The oil essential derived from both fruits/seeds and leaves exhibits important activity against a wide spectrum of microorganisms, including Gram-positive and Gram-negative bacteria, yeast-like and filamentous fungi. Notably, *C. sativum* oil demonstrates effective antibiofilm activity against *Candida* spp., *E. coli, S. aureus* and oral pathogens, especially *Streptococcus* species.

Recent advancements include nanoencapsulation techniques applied to free oil or major oil compounds such as linalool, which have shown promising outcomes. These formulations can be explored both in the development of antimicrobial drugs, or as a potential antimicrobial agent for sterilization of hospital equipment, as well as for preventing contamination in the food industry.

In conclusion, the essential oils of various parts of *C. sativum*, as well as their constituents, can be considered as treatments for infectious diseases caused by bacteria and fungi of great clinical importance. However, further studies should explore the mechanisms of activity and cytotoxic effects.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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