Biological activities of essential oils: a mini-review

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Abstract. Essential oils (EOs) are derived from plants and exhibit diverse biological activities, including antiviral, anticancer and antimicrobial effects. This review offers a thorough examination of their chemical composition and biological properties, which are crucial for pharmaceutical, medical, and agricultural applications. EOs exhibit potent antimicrobial action against various bacteria and fungi, including drug-resistant strains, and display promising antiviral activity against influenza, herpes, and HIV. Additionally, they show potential as anticancer agents, inducing apoptosis and inhibiting cell proliferation. Despite their benefits, challenges such as low solubility and stability limit their use. Innovative strategies such as nanoencapsulation aim to enhance their efficacy.
Keywords: Biological activity, antimicrobial agent, essential oil, anti-cancer activity.

1 Introduction

Essential oils (EOs) are defined as a natural complex bends of biologically active volatile compounds. These EOs are commonly derived from aromatic plants across different plant parts such as flowers, seeds, roots, leaves and bark. Plants produce essential oils as secondary metabolites, serving as crucial agents in regulating plant growth and managing plant health by effectively combating various plant pests such

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as bacteria, fungi, viruses, nematodes, and insects, while also serving as deterrents to herbivores [1].

Owing to their biological properties, low toxicity, and cost-effective extraction methods, plant-based essential oils and their constituents are currently garnering interest across various sectors, including pharmaceuticals, medicine, commercial foods, and agriculture. Extensive research conducted at molecular, cellular, and animal levels has highlighted the considerable potential and effectiveness of essential oils in multiple scientific fields [2]. These oils exhibit a broad biological profile, encompassing antioxidant, antimicrobial, antiviral, anticancer, and anti-inflammatory activities, among others. Essential oils contain a diverse range of compounds, including alcohols, phenols, ketones, esters, aldehydes and hydrocarbons. The activity of these compounds arises from their synergistic interaction to produce beneficial effects [3], and they demonstrate efficacy when evaluated individually. For instance, essential oils obtained from various Thymus species have been shown to possess antimicrobial, antioxidant, immune-boosting, and antitumor properties [4, 5]. A recent study have also demonstrated that terpenes and cannabinoids extracted from *Cannabis sativa* exhibit antiviral effects against human coronaviruses and influenza A virus (H1N1)[6]. Leveraging their antiviral, antioxidant, and antimicrobial properties, essential oils find applications in food preservation and packaging, as well as in agriculture as biopesticides agents. Essential oils face challenges such as low water solubility, low stability under fluctuating environmental conditions such as temperature, light and oxygen, and toxicity at high concentrations [7]. As a result, there is a growing trend in research to develop nanoecapsulation of essential oils, in order to improve their functionality and expand their applications.

This review presents a comprehensive analysis of current scientific literature, shedding light on the principal biological properties of essential oils including antimicrobial, antiviral, and anticancer activities. This article aims to consolidate and contextualize existing understanding on the biological effects of plant essential oils, serving as a comprehensive guide for researchers, healthcare professionals, and industries interested in these versatile natural substances.

2 Chemical composition of Essential Oils (EOs)

Essential oils are characterized by their potent scent and flavour, low toxicity, and cost-effective extraction methods, plant-based essential oils and their constituents which can vary based on the specific chemical composition of the oil (figure 1). This composition varies across plant species and taxa. Numerous factors, such as soil characteristics, climatic conditions, and phenological stage of plant, exert influence over the chemical constitution of plant-base oils. In general, these oils comprise a diverse array of polar and non-polar components, with only a few dominant ones found at relatively high concentrations (20–90%), while others are present in lower amounts [8]. This complex mixture can be further categorized into two main groups based on their biosynthetic origin: terpenes and aromatic/aliphatic compounds. Terpenes, formed from isoprene units, constitute the primary fraction of essential oils, with various subgroups classified by the number of isoprene subunits they contain [9]. Monoterpenes, in particular, are often the predominant molecules, comprising up to 90% of the total oil. Conversely, aromatic and aliphatic compounds, including alcohols, aldehydes, phenols, and heterocycles, are less abundant in essential oils [10, 9]. Notably, phenolic compounds like carvacrol, thymol, and eugenol play a crucial role in the oils' antimicrobial properties [11]. The chemical composition of essential oils is highly variable, influenced by factors such as harvest time, geographic origin, plant part, and maturity level [10]. For instance, the composition of coriander essential oils differs significantly between seeds and leaves, with the predominant compound, linalool, accounting for 70% in seeds but only 26% in leaves [1].

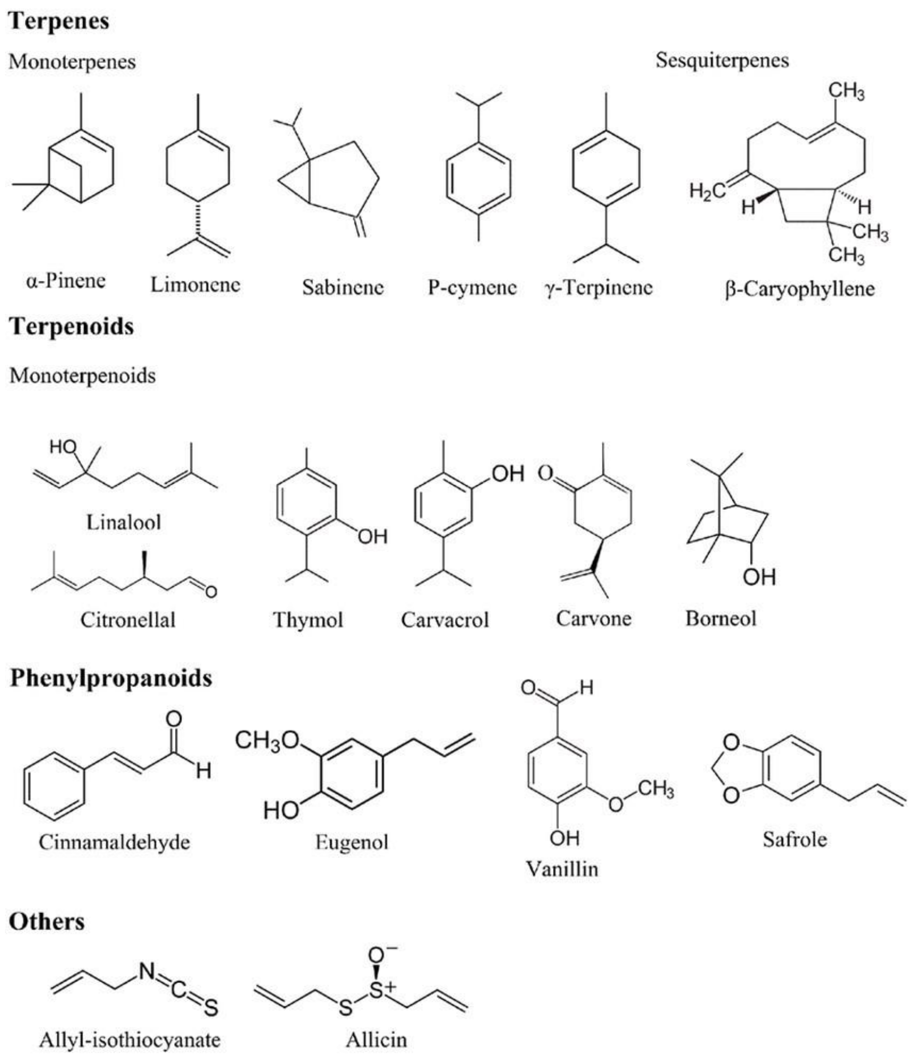

Fig. 1. Chemical structures of some EOs compounds.

3 Biological activities of Essential oils

Essential oils exhibit a board range of biological activities. These include mainly antimicrobial, antiviral, anticancer, anticancer, and antioxidant (figure 2).
Essential oils are composed of various bioactive molecules like monoterpenes, sesquiterpenes, oxygenated monoterpenes, oxygenated sesquiterpenes, and phenolics, which contribute to their therapeutic effects. Specific components in essential oils, such as thymol, citronellal, carvone, zingiberene, carvacrol and others, play key roles in activities like antioxidant, anti-inflammatory, antimicrobial, and cytotoxic effects. The biological activities of essential oils are attributed to the synergistic effects of their active ingredients, making them valuable in various field applications.

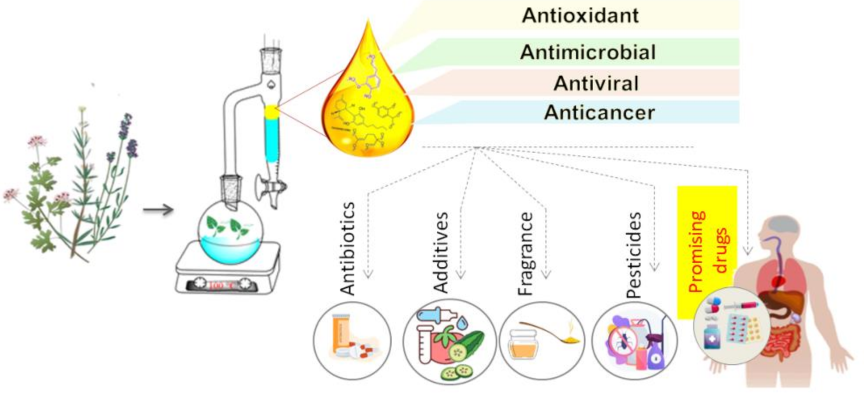

Fig. 2. Principal biological activities of essential oils.

3.1 Antimicrobial properties

Antimicrobial properties are the basis for the application of essential oils in various sectors such as cosmetics, food, perfumery and pharmaceuticals. Recently, essential oils have become increasingly popular as an interesting alternative to synthetic chemicals for the control of foodborne, pathogenic and phytopathogenic microorganisms. Essential oils have been shown to be successful in inhibiting the growth of many fungal and bacterial strains, including antibiotics resistant strains.

3.1.1 Antibacterial effects

A multitude of studies have been conducted on the antibacterial efficacy of essential oils, which have been found to possess antibacterial properties against both pathogenic and non-pathogenic bacteria [12]. This effectiveness has been examined and demonstrated against diverse bacterial strains, including *Escherichia coli*, *Lactobacillus plantarum*, *Staphylococcus aureus*, *Pseudomonas aeruginosa, Listeria monocytogenes, Bacillus subtilis*, *Saccharomyces cerevisiae and Salmonella enterica* , among others. Notably, essential oils derived from three citrus species have been found to exhibit significant inhibitory effects on methicillin-resistant Staphylococcus [13]. In a separate study, essential oils from oregano species have been shown to possess antibacterial activity against *Haemophilus influenzae* and *Haemophilus parainfluenzae* biofilms [14]. Generally, essential oils enriched with aldehydes or phenols, such as linalool, citral, carvacrol, eugenol, or thymol, have been found to exhibit higher antibacterial activity. Essential oils and their constituents have been demonstrated to inhibit bacterial growth through a variety of mechanisms, exerting an antibacterial effect. For instance, phenolic essential oil constituents, such as carvacrol and thymol, interact with different regions of bacterial cells, leading to membrane disruption and subsequent cell death [15]. Examination of essential oils from *Citrus medica* against *Staphylococcus aureus* has revealed the formation of pores on the bacterial surface and plasma membrane disruption [16]. It is noteworthy that some essential oils may also exhibit mutagenic activity. The essential oil of *Lippia graveolens* has been demonstrated to exert an inhibitory effect on the formation of *Acinetobacter Baumanni* formation, affecting twitwching motility [17].

3.1.2 Antifungal effects

The antifungal activities of essential oils and their constituents are multifaceted, targeting various aspects of fungal cell structures essential for survival. Extracted from plants like oregano, thyme, rosemary, clove, cinnamomum, basil, and others, these oils exhibit significant antifungal potential against a diverse array of plant pathogens. Research by Pinto et al. highlights the inhibitory effects of Thymus pulegiosides EO on numerous Candida species; *C. albicans*, *C. guillermondii*, *C. parapsilosis*, C. *krusei*, and *C. glabrata* [18]. Similarly, garlic and clove essential oils have been shown to have antifungal inhibitory effects against *C. albicans C. acutus*, *C. catenulata*, *C. apicola*, *C. tropic*alis, *C. inconspicua*, and other fungal species [19]. In another study, oregano and thyme essential oils have shown high inhibition effects on fungal pathogens, attributed to their constituents such as carvacrol and thymol, which disrupt fungal cell membranes [20]. Delaquis and Mazza have reported the antimicrobial effects of chemical irritants found in essential oils from onion and garlic plants, suggesting that isothiocyanates may deactivate extracellular enzymes through oxidative cleavage of disulfide bonds, effectively combating *Botrytis*, *Fusarium*, and *Cladosporium* species. Moreover, essential oils impact fungal cell structures, including the plasma membrane and cell wall, through mechanisms such as ergosterol modulation, direct ergosterol binding, and inhibition of cell wall synthesis enzymes [21]. The action of essential oils on fungal micromorphology, such as reducing hyphal development, further contributes to their antifungal efficacy. Compounds like linalool and gamma-terpinene found in certain oils, such as *Coriandrum sativum L*., also play a significant role in their antifungal activity [22]. Overall, essential oils offer a rich source of compounds with diverse mechanisms of action, providing promising avenues for combating fungal pathogens effectively.

3.2 Antiviral properties

Besides antimicrobial properties, essential oils have also been shown to possess potent antiviral activities against a diverse range viruses. These include influenza virus (IFV), herpesvirus (HSV), poliovirus, coxsackievirus, yellow fever virus, and human immunodeficiency virus (HIV) and others. The antiviral efficacy of essential oils from *Lippia junelliana* and *Artemisia douglasiana* has been demonstrated against the dengue virus and Junin virus, respectively [13]. Furthermore, the vapor of essential oils obtained from *Citrus bergamia*, *Eucalyptus globulus*, and their isolated constituents, such as eugenol and citronellol, demonstrates rapid anti-IFV effects [24]. In vitro assays have revealed that essential oils extracted from tea, thyme, and eucalyptus exhibit notable activity against herpes simplex virus type 1 (HSV-1), with an inhibition rate of approximately 96% [25]. A study conducted by Mediouni et al. (2020) revealed the inhibitory effect of carvacrol and thymol, obtained from oregano, on the fusion of host cells infected with human immunodeficiency virus type 1 (HIV-1), thus preventing the virus from entering the host system by reducing cholesterol within the viral envelope membranes. Essential oils exert their antiviral effects through various mechanisms, primarily by directly acting on free viruses, inhibiting virus attachment, penetration and replication [26],16] .Additionally, they inhibit vital viral enzymes [26]. The latest literature suggests that essential oils may have the potential to act as effective antiviral therapeutic agents for SAR-CoV-2, due to their ability to reduce inflammatory factors [28]. Several studies indicate that essential oils may attenuate ACE2 [18, [30], a key receptor of SARS-CoV-2. Clementine essential oil, with its major compound limonene, shows a strong binding affinity to the SARS-CoV-2 spike protein in silico [31]. It's worth noting that some essential oil compounds can reduce the characteristic symptoms associated with some viral infections. For example, the anti-influenza compound 1,8-cineol has been shown to reduce exacerbations and dyspnoea in COPD patients [32] , as well as nasal obstruction and secretion in patients with acute rhinosinusitis [33].

3.3 Anti-cancer properties

The anticancer potential of essential oils has been extensively studied and documented. More than a hundred essential oils from different plant have been tested on various types of cancers, demonstrating their potential as promising anticancer agents in treating various types of cancer such as leukemia, breast, lung, ovarian, liver, and colon cancers. The mechanisms involved in their anticancer activities include inducing apoptosis, inhibiting cell proliferation, disrupting mitochondrial function, modulating cell cycle progression, and inducing oxidative damage to tumor cells [34] . For example, essential oil (EO) derived from *Allium sativum* L. bulbs exhibited cytotoxicity against leukemia cells by increasing ROS levels and inducing apoptosis and differentiation [35]. Similarly, *Zataria multiflora Boiss*. EO induced apoptosis in colon cancer cells by elevating ROS levels [36]. *Litsea cubeba (*Lour.) Pers. seed EO prompted apoptotic cell death by suppressing the AKT/mTOR pathway [37]. Essential oils contain several bioactive compounds, such as carvacrol, thymol, eugenol, cinnamaldehyde, geraniol, β-pinene, α-pinene, camphor, cedrol, and verbenol, which exhibit potent antitumor properties, especially when present in high levels. Moreover, essential oils have been found to modulate multidrug resistance and exhibit synergistic mechanisms of volatile constituents. These biological activities have been observed in both in vitro and in vivo studies, highlighting a promising area of research for the development of new cancer treatments based on essential oils.

4 Conclusion

Essential oils represent a rich source of biologically active compounds with diverse therapeutic properties. Their antimicrobial, antiviral, anticancer, and antioxidant effects, driven by complex chemical compositions, offer promising avenues for applications in pharmaceuticals, medicine, food preservation, and agriculture. Despite challenges such as low water solubility and environmental instability, ongoing research endeavors aim to enhance their efficacy and expand their utility. EOs from various plant species exhibit potent antimicrobial and antiviral activities against a range of pathogens, alongside notable anticancer and anti-inflammatory effects, highlighting their potential as powerful promising therapeutic drugs.

References

[1] P. Delaquis, 'Antimicrobial activity of individual and mixed fractions of dill, cilantro, coriander and eucalyptus essential oils', *Int. J. Food Microbiol.*, vol. 74, no. 1–2, pp. 101–109, Mar. 2002, doi: 10.1016/S0168-1605(01)00734-6.

[2] M. Kulig, A. Galanty, K. Grabowska, and I. Podolak, 'Assessment of safety and health-benefits of Citrus hystrix DC. peel essential oil, with regard to its bioactive constituents in an in vitro model of physiological and pathological skin conditions', *Biomed. Pharmacother.*, vol. 151, p. 113151, Jul. 2022, doi: 10.1016/j.biopha.2022.113151.

[3] S. Chouhan, K. Sharma, and S. Guleria, 'Antimicrobial Activity of Some Essential Oils—Present Status and Future Perspectives', *Medicines*, vol. 4, no. 3, p. 58, Aug. 2017, doi: 10.3390/medicines4030058.

[4] F. Z. Radi *et al.*, 'Phytochemical Analysis, Antimicrobial and Antioxidant Properties of Thymus zygis L. and Thymus willdenowii Boiss. Essential Oils', *Plants*, vol. 11, no. 1, p. 15, Dec. 2021, doi: 10.3390/plants11010015.

[5] S. Benedetti, M. G. Nasoni, F. Luchetti, and F. Palma, 'New insights into the cytotoxic effects of Thymus vulgaris essential oil on the human triple-negative breast cancer cell line MDA-MB-231', *Toxicol. In Vitro*, vol. 93, p. 105705, Dec. 2023, doi: 10.1016/j.tiv.2023.105705.

[6] L. Chatow *et al.*, 'Terpenes and cannabidiol against human corona and influenza viruses–Anti-inflammatory and antiviral in vitro evaluation', *Biotechnol. Rep.*, vol. 41, p. e00829, Mar. 2024, doi: 10.1016/j.btre.2024.e00829.

[7] A. Maurya, J. Prasad, S. Das, and A. K. Dwivedy, 'Essential Oils and Their Application in Food Safety', *Front. Sustain. Food Syst.*, vol. 5, p. 653420, May 2021, doi: 10.3389/fsufs.2021.653420.

[8] J. S. Raut and S. M. Karuppayil, 'A status review on the medicinal properties of essential oils', *Ind. Crops Prod.*, vol. 62, pp. 250–264, Dec. 2014, doi: 10.1016/j.indcrop.2014.05.055.
[9] R. Pavela, 'Essential oils for the development of eco-friendly mosquito larvicides: A review', *Ind. Crops Prod.*, vol. 76, pp. 174–187, Dec. 2015, doi: 10.1016/j.indcrop.2015.06.050.
[10] W. Dhifi, S. Bellili, S. Jazi, N. Bahloul, and W. Mnif, 'Essential Oils' Chemical Characterization and Investigation of Some Biological Activities: A Critical Review', *Medicines*, vol. 3, no. 4, p. 25, Sep. 2016, doi: 10.3390/medicines3040025.
[11] S. Burt, 'Essential oils: their antibacterial properties and potential applications in foods—a review', *Int. J. Food Microbiol.*, vol. 94, no. 3, pp. 223–253, Aug. 2004, doi: 10.1016/j.ijfoodmicro.2004.03.022.
[12] T. M. Osaili *et al.*, 'A Status Review on Health-Promoting Properties and Global Regulation of Essential Oils', *Molecules*, vol. 28, no. 4, p. 1809, Feb. 2023, doi: 10.3390/molecules28041809.
[13] S. Bhavaniramya, S. Vishnupriya, M. S. Al-Aboody, R. Vijayakumar, and D. Baskaran, 'Role of essential oils in food safety: Antimicrobial and antioxidant applications', *Grain Oil Sci. Technol.*, vol. 2, no. 2, pp. 49–55, Jun. 2019, doi: 10.1016/j.gaost.2019.03.001.
[14] B. Piasecki *et al.*, 'Microbiological Studies on the Influence of Essential Oils from Several Origanum Species on Respiratory Pathogens', *Molecules*, vol. 28, no. 7, p. 3044, Mar. 2023, doi: 10.3390/molecules28073044.
[15] I. M. Helander *et al.*, 'Characterization of the Action of Selected Essential Oil Components on Gram-Negative Bacteria', *J. Agric. Food Chem.*, vol. 46, no. 9, pp. 3590–3595, Sep. 1998, doi: 10.1021/jf980154m.
[16] Z.-H. Li, M. Cai, Y.-S. Liu, P.-L. Sun, and S.-L. Luo, 'Antibacterial Activity and Mechanisms of Essential Oil from Citrus medica L. var. sarcodactylis', *Molecules*, vol. 24, no. 8, p. 1577, Apr. 2019, doi: 10.3390/molecules24081577.
[17] M. R. Tapia-Rodriguez, E. U. Cantu-Soto, F. J. Vazquez-Armenta, A. T. Bernal-Mercado, and J. F. Ayala-Zavala, 'Inhibition of Acinetobacter baumannii Biofilm Formation by Terpenes from Oregano (Lippia graveolens) Essential Oil', *Antibiotics*, vol. 12, no. 10, p. 1539, Oct. 2023, doi: 10.3390/antibiotics12101539.
[18] E. Pinto *et al.*, 'Antifungal activity of the essential oil of Thymus pulegioides on Candida, Aspergillus and dermatophyte species', *J. Med. Microbiol.*, vol. 55, no. 10, pp. 1367–1373, Oct. 2006, doi: 10.1099/jmm.0.46443-0.

[19] D. S. Arora and J. Kaur, 'Antimicrobial activity of spices', *Int. J. Antimicrob. Agents*, vol. 12, no. 3, pp. 257–262, Jul. 1999, doi: 10.1016/S0924-8579(99)00074-6.

[20] A. Ultee and E. J. Smid, 'Influence of carvacrol on growth and toxin production by Bacillus cereus', *Int. J. Food Microbiol.*, vol. 64, no. 3, pp. 373–378, Mar. 2001, doi: 10.1016/S0168-1605(00)00480-3.

[21] L. J. Danielli *et al.*, 'Antifungal mechanism of action of *Schinus lentiscifolius* Marchand essential oil and its synergistic effect *in vitro* with terbinafine and ciclopirox against dermatophytes', *J. Pharm. Pharmacol.*, vol. 70, no. 9, pp. 1216–1227, Aug. 2018, doi: 10.1111/jphp.12949.

[22] J. Tian, X. Ban, H. Zeng, J. He, Y. Chen, and Y. Wang, 'The Mechanism of Antifungal Action of Essential Oil from Dill (Anethum graveolens L.) on Aspergillus flavus', *PLoS ONE*, vol. 7, no. 1, p. e30147, Jan. 2012, doi: 10.1371/journal.pone.0030147.

[23] C. R. Venturi *et al.*, 'Chemical analysis and *in vitro* antiviral and antifungal activities of essential oils from *Glechon spathulata* and *Glechon marifolia*', *Pharm. Biol.*, vol. 53, no. 5, pp. 682–688, May 2015, doi: 10.3109/13880209.2014.936944.

[24] M. Asif, M. Saleem, M. Saadullah, H. S. Yaseen, and R. Al Zarzour, 'COVID-19 and therapy with essential oils having antiviral, anti-inflammatory, and immunomodulatory properties', *Inflammopharmacology*, vol. 28, no. 5, pp. 1153–1161, Oct. 2020, doi: 10.1007/s10787-020-00744-0.

[25] A. Astani, J. Reichling, and P. Schnitzler, 'Comparative study on the antiviral activity of selected monoterpenes derived from essential oils', *Phytother. Res.*, vol. 24, no. 5, pp. 673–679, May 2010, doi: 10.1002/ptr.2955.

[26] L. Ma and L. Yao, 'Antiviral Effects of Plant-Derived Essential Oils and Their Components: An Updated Review', *Molecules*, vol. 25, no. 11, p. 2627, Jun. 2020, doi: 10.3390/molecules25112627.

[27] P. Schnitzler, A. Astani, and J. Reichling, 'Antiviral Effects of Plant-Derived Essential Oils and Pure Oil Components', in *Lipids and Essential Oils as Antimicrobial Agents*, 1st ed., H. Thormar, Ed., Wiley, 2011, pp. 239–254. doi: 10.1002/9780470976623.ch10.

[28] G. Asaad, M. Abdelhameed, M. Elraey, W. Roshdy, A. Elgamal, and Y. Moamen, 'Citrus clementine peels essential oil exhibited anti-SARS-CoV-2 and its modulatory effect against cytokine storm: Evidence from in vitro and in silico studies', *Egypt. J. Chem.*, vol. 0, no. 0, pp. 0–0, Jan. 2022, doi: 10.21608/ejchem.2022.116657.5271.

[29] F. Demirci, A. E. Karadağ, S. N. Biltekin, and B. Demirci, '*In Vitro* ACE2 and 5-LOX Enzyme Inhibition by Menthol and Three Different Mint

Essential Oils', *Nat. Prod. Commun.*, vol. 16, no. 11, p. 1934578X2110550, Nov. 2021, doi: 10.1177/1934578X211055014.

[30] A. E. Karadağ, F. Demirci, S. N. Biltekin, and B. Demirci, 'In vitro ACE2 and 5-LOX Inhibition of Rosmarinus officinalis L. Essential Oil and its Major Component 1,8-Cineole', *Rec. Nat. Prod.*, no. 2, pp. 194–199, Aug. 2021, doi: 10.25135/rnp.265.21.05.2080.

[31] P. González-Maldonado *et al.*, 'Screening of Natural Products Inhibitors of SARS-CoV-2 Entry', *Molecules*, vol. 27, no. 5, p. 1743, Mar. 2022, doi: 10.3390/molecules27051743.

[32] H. Worth, C. Schacher, and U. Dethlefsen, 'Concomitant therapy with Cineole (Eucalyptole) reduces exacerbations in COPD: A placebo-controlled double-blind trial', *Respir. Res.*, vol. 10, no. 1, p. 69, Dec. 2009, doi: 10.1186/1465-9921-10-69.

[33] W. Kehrl, U. Sonnemann, and U. Dethlefsen, 'Therapy for Acute Nonpurulent Rhinosinusitis With Cineole: Results of a Double-Blind, Randomized, Placebo-Controlled Trial', *The Laryngoscope*, vol. 114, no. 4, pp. 738–742, Apr. 2004, doi: 10.1097/00005537-200404000-00027.

[34] F. Mohamed Abdoul-Latif, A. Ainane, I. Houmed Aboubaker, J. Mohamed, and T. Ainane, 'Exploring the Potent Anticancer Activity of Essential Oils and Their Bioactive Compounds: Mechanisms and Prospects for Future Cancer Therapy', *Pharmaceuticals*, vol. 16, no. 8, p. 1086, Jul. 2023, doi: 10.3390/ph16081086.

[35] S. F. T. Agassi, T.-M. Yeh, C.-D. Chang, J.-L. Hsu, and W.-L. Shih, 'Potentiation of Differentiation and Apoptosis in a Human Promyelocytic Leukemia Cell Line by Garlic Essential Oil and Its Organosulfur Compounds', *Anticancer Res.*, vol. 40, no. 11, pp. 6345–6354, Nov. 2020, doi: 10.21873/anticanres.14655.

[36] N. Ahani, M. H. Sangtarash, M. Alipour Eskandani, and M. Houshmand, 'Zataria multiflora Boiss. Essential Oil Induce Apoptosis in Two Human Colon Cancer Cell Lines (HCT116 & SW48)', *Iran. J. Public Health*, vol. 49, no. 4, pp. 753–762, Apr. 2020.

[37] S. Seal *et al.*, 'Vapor of Volatile Oils from Litsea cubeba Seed Induces Apoptosis and Causes Cell Cycle Arrest in Lung Cancer Cells', *PLoS ONE*, vol. 7, no. 10, p. e47014, Oct. 2012, doi: 10.1371/journal.pone.0047014.