Chapter 22

The Potential of Essential Oils as Antiviral, Antioxidant and Immunomodulatory Agent

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ABSTRACT

The aim of this chapter is to take a view and highlight the different biological properties of essential oils. Since ancient times, essential oils (EOs) have been used for many medicinal and preservative purposes. But now, they are increasingly studying to treat various diseases. Current antibiotics and antivirals have a major issue which is resistance, which can be resolved by using natural compounds. EOs are herbal volatile oils derived from plants through various extraction methods. Pharmacologically, they are very active and exhibit wonderful characteristics like preservatives, flavoring agents, antimicrobials, antiseptics, anti-inflammatory, antioxidants, immunomodulatory, antiviral, etc. Each bioactive component in the EOs has its properties and performs various functions in the body. EOs show antiviral activity by binding to the free viruses and inhibiting their multiplication. Phenolic and oxygenated compounds of EOs are responsible for antioxidant activity because of the presence of double bonds. Immunomodulatory properties of EOs are manifested majorly by the modification in the release of cytokines. These applications highlight the scope of EOs in the modern world.

KEYWORDS
essential oil, Antiviral, Antioxidant, Immunomodulatory

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INTRODUCTION

Medicines used in humans and animals are prone to bacterial resistance and side effects like allergic reactions (Arsène et al., 2022). That's why researchers are studying natural compounds that have less toxicity and resistance issues because of broad-spectrum mechanisms of action. These compounds are obtained from plants or natural sources. Essential oils (EOs) are one of them which is our topic of discussion. EOs are highly concentrated, colorless aromatic oils derived from plants, and used for medicine in diluted form (Bakkali et al., 2008). Plants synthesize them through various extraction processes which are solvent extraction, steam vaporization, enfleurage, cold pressing, maceration, and distillation (Shikov et al., 2022). The bioactive compounds present in them enable them to show various characteristics like antimicrobial, antiseptic, insecticidal, antitumor, immunomodulatory, antioxidant, etc. (Murbach Teles Andrade et al., 2014). In this chapter, we will cover the antiviral, antioxidant, and immunomodulatory aspects of essential oils in the aforementioned sections that are very frequently used in our daily lives.

EOs

EOs are the intricate combinations of monoterpenes and sesquiterpenes (C10 and C15 respectively), phenylpropanoids, and oxygenated compounds (aldehydes, alcohols, and ketones) (Yingngam, 2022). They are hydrophobic in nature, soluble in alcohol, oils, ether, and waxes, and slightly soluble in water, as are weak polar solvents. The function of EOs depends upon the chemistry (functional groups and composition) of EOs. EOs have an intense odor. They are secondary metabolites of plants that help them in their fight against pathogens and attraction for insects that help in communication between plants through pollination, that's why explored in the field of medicine (Manion and Widder, 2017). EOs are also known as plant essences, used in aromatherapy, which means the usage of aromatic oils as therapeutic agents (A. Sharma et al., 2023). Thousands of EOs are well known and many of them are commercially available. It includes many groups like terpenes, monoterpenes, sesquiterpenes, carotenoids, aldehydes, flavonoids, phenols, oxides, hydrocarbons, volatile compounds (esters, alcohol, and alkenes) etc. Each EO consists of numerous

bioactive compounds in them that produce or show their effect according to the chemical structure. Phenols consist of thymol, carvacrol, and eugenol (Chouhan et al., 2017). Various EOs along with their bioactive components are represented in the Fig. 1. These bioactive compounds constitute antimicrobial contents and flavors as they contain proteins, vitamins, and heterocyclic compounds.

Most widely customized aromatic oils are derived from oregano, peppermint, spearmint, mustard, lemon, thyme, lavender, eucalyptus, dill, cinnamon, rose, orange, clove, tea extracts, etc. (Mohammed et al., 2024). EOs can be obtained from every part of the plant, like leaves, bark, roots, shoots, twigs, wood, fruits, flowers, seeds, etc. from these parts of plants (Hanif et al., 2019). EOs can be extracted through the above-mentioned processes. Each process produces EOs of different compositions in quality and quantity. The type of method is selected on the basis of the purpose of the application. Because of its numerous properties, they are extensively used as flavoring, aroma, antimicrobial, and therapeutic agents. EOs enhance the shelf life and quality of edible products (Pérez-Santaescolástica et al., 2022). Biological properties enable them to act as antiviral, antifungal, antiparasitic, antibacterial, antidepressant, antioxidant, immunomodulatory, and insecticidal. They can be used in the form of oils, capsules, powders, lotions, ointments, creams, etc.

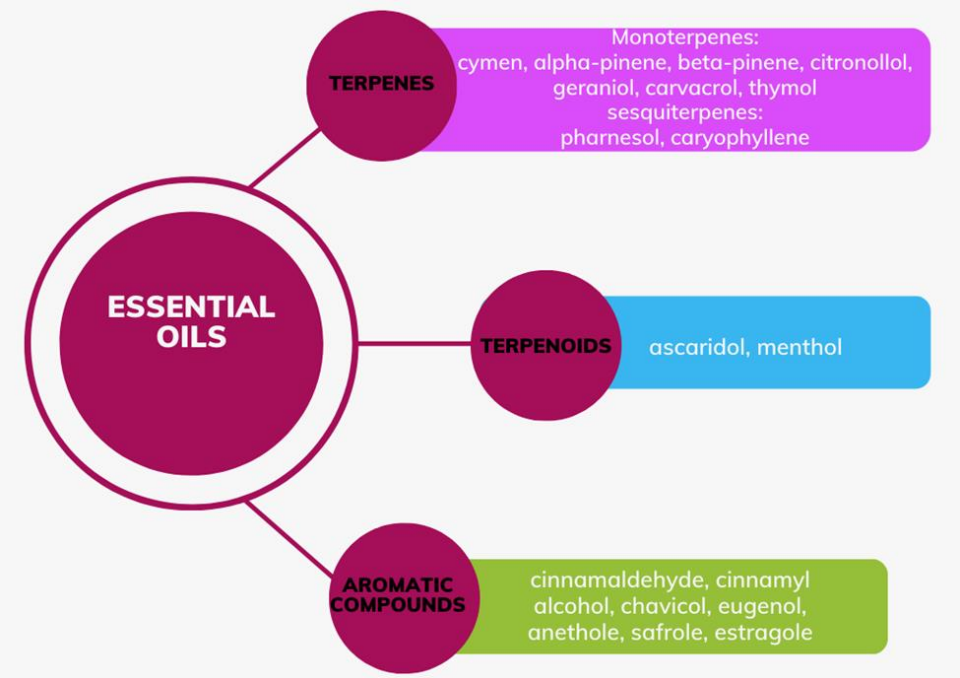

Fig. 1: EOs and its Classifications

History of essential oils

It is hard to find the exact discovery and first usage of EOs. Empirically, they are used to wipe off the foul odor and preserve or flavor the foods. These EOs have high economic and cultural importance. They have been in use since BCE, but reported medicinal use started later. In 1912, Gattefosse's hand was burned in a lab burst, he dipped his hand in lavender oil and got healing (Buckle, 2002). Paracelsus von Hohenheim coined the term EOs from a drug named Quinta Essentia (Brenner, 1993). Later on, the processes of its extraction are discussed, and they became industrially commercialized for use in cosmetics and therapeutics.

Critical Analysis

Synergism within EOs' Components

EOs are complex mixtures of different compounds and produce a combined effect (Sheng et al., 2020). The combined effect is the effect of all the major and minor components present in the EOs. These minor components possess synergistic effects, and the resultant effect is represented as the effect of the main component (Saad et al., 2013). All components together identify the cell penetration, density, fragrance, color, and texture of each EO. These minor components, in addition to synergistic effects, can also pose antagonistic or additive effects. The synergistic effect provides broad-spectrum activity and increased efficacy to EO (Ju et al., 2022). Two or more compounds synergistically are used to produce flavor and aroma without causing adverse effects.

Administration Routes

The most widely employed routes of administration include oral, inhalation, and topical. In the topical route, EOs in small quantities are mixed with some base or carrier and massaged on the skin (Guzmán and Lucia, 2021). A very small quantity is required that can produce its effect pronouncedly (Baldim et al., 2021). Very frequently used in lotions, ointments, and creams. In inhalation, there is stimulation of olfactory nerves either through sprays, inhalation through bottles, or baths (Rowland, 2024). This is used to enhance a balance of physical and mental state. It is widely reported that

EOs show maximum effects in both humans and animals.

Some oils cause toxicity, so should be administered with precautions, oral route shows maximum effect due to exposure to the lymphatic system through the gastrointestinal system (Baptista-Silva et al., 2020). It shows its mechanism in three ways viz; in biochemical mechanism, it transfers through blood in the whole body and interacts with hormones and enzymes (Cimino et al., 2021). In psychological innervation of the brain occurs through olfactory stimulation and then shows its effect on mental health by producing neurotransmitters. In physiological mechanisms, oils act on specific systems of the body and perform a therapeutic function (Sadgrove et al., 2021). Precautions should be undertaken while using these because higher doses cause adverse effects.

Essential oils as Antiviral Agents

Phenols and aldehydes have the ability to initiate immune responses. Lemon, eucalyptus, cinnamon, tea tree (TT), clove, peppermint, garlic, etc. are involved in antiviral activity. EOs act by boosting the weakened immune system (Zuo et al., 2020). The mechanism of action depends upon the interaction of EOs either outside or inside of the cell with free viruses (Ma and Yao, 2020). They act by making changes in the structure of the virus and hiding their proteins (Reichling, 2022). There are various mechanisms of action that depend on the type of EOs, for example, carvacrol acts by hiding the capsid or by binding to the virus (Javed et al., 2021). Isothymol derived from *Ammoides verticillate* inhibits the COVID-19 receptor, which is angiotensin converting enzyme 2 (Abdelli et al., 2021). EOs are effective against many viruses like respiratory syncytial, bovine viral diarrhea, yellow fever, Zika, and alpha herpes viruses, and many others (K. Sharma et al., 2023) which are as follows: Germacron EOs are involved in antiviral activity against feline caliciviruses (K. Sharma et al., 2023). EOs derived from Australian TT, Star Anise, piperitenone, *Eucalyptus caesia*, *Zingiber officinale,* oregano, and eugenol, 1,8 cineole showed antiviral activity against HSV-1 (El Gendy et al., 2022). While EOs derived from *Savia desoleana*, germacrene D, linalool, linalyl acetate, 1,8 cineole, α-terinyl acetate, and β-caryophyllene, showed antiviral activity against HSV-2 (Sharifi-Rad et al., 2017). EOs like β-santalol, clary sage, 1,8 cineole, marjoram, terpinene-4-ol, anise EOs, citrus *bergamia, Cinnamomum zeylanicum,* and *Thymus vulgaris* showed antiviral efficacy against influenza virus (Vimalanathan and Hudson, 2014). EOs from cedar leaf are very effective against the hemagglutinin protein of the influenza virus (Oriola and Oyedeji, 2022, Mustafa et al., 2023) . Oregano with its major component carvacrol, has antiviral activity against norovirus and rotavirus (Sarowska et al., 2021). Isothymol and 1,8 cineole are effective against COVID-19 (Nadjib, 2020; Soleymani et al., 2022). Oxygenated EOs have proved effective against influenza virus while non-oxygenated against HSV.

Essential oils as Immunomodulatory Agents

The process of increasing or decreasing the immune system is known as immunomodulation. EOs show an immunomodulatory effect by expressing interleukins through lymphocyte proliferation and modulating inflammation by stimulating phagocytic activity (Pelvan et al., 2022). EOs help in initiating the immune response against pathogens by activating the immune system, which consists of innate and adaptive immune systems (Grazul et al., 2023). The innate immune system consists of dendritic cells, monocytes, and macrophages, and is involved in the primary defense mechanism by initiating inflammatory immune responses (Zhao et al., 2023). Adaptive immune systems include dendritic cells, macrophages, neutrophils, natural killer cells, eosinophils, basophils, B and T cells, etc. (Akhand and Ahsan, 2023). Is stimulated by the EO activity by cytokine release and phagocytosis. Pattern recognition receptors recognize the pathogen-associated molecular patterns and induce innate immune cells to inflammation that, in turn activate the adaptive immune system (Singh et al., 2023). T cells on stimulation, differentiate into $CD4^+$ (Th1) and $CD8^+$ Th cells that produce cytokines. Th2 cells differentiate into B cells that produce antibodies to neutralize pathogens (Zuo et al., 2020). Many therapeutic EOs like lemon grass and balm, clove, black cumin, eucalyptus, marjoram, rose, fennel, lavender, thyme, sage, TT, bay laurel, peppermint, etc. are involved in immunomodulatory and anti-inflammatory effects (Tirant et al., 2024). Oropharyngeal candidiasis produces IL-8 which is inhibited by TT oil (Sosa et al., 2023). TT oil also exerts an effect on hypersensitivity and histamine-induced edema. Eugenol is involved in the inhibition of IL-1β,6,10, and lipopolysaccharide inflammatory action through the mechanism of inhibiting the nuclear factor Kappa β pathway (Saini and Dhiman, 2022). Parsley shows an effect on inflammation by inhibiting the proliferation of phytohemagglutinin-stimulated splenocytes (Yousofi et al., 2012). In a study of clove bud and cinnamon bark, EOs proved effective in combating Newcastle disease and were involved in increasing intestinal villi length (Sandner et al., 2020). Ginseng is involved in immunostimulants by the production of IFN-γ and TNF-α. TT EOs enhance intestinal immunity by releasing IL-2, IL-10, and IFN-γ and also enhance growth performance, and reduce the incidence of diarrhea in small pigs (Zhu et al., 2018). Clove EOs was studied *in vitro,* and showed cellular and humoral immunity in immunocompetent and immunosuppressed mice respectively (Peterfalvi et al., 2019). Herbal EOs have been researched in various studies and resulted in the best remedies for reducing inflammation by modifying inflammatory cytokines (de Lavor et al., 2018). Sandner et al., 2020 reviewed that EOs can be alternative to antibiotics for use in broilers.

Essential oils as Antioxidant Agents

EOs like monoterpenes, sesquiterpenes, and oxygenated derivatives have different chemical structures that enable them to act as antioxidants (Bhavaniramya et al., 2019). The EOs which have a scavenging effect on reactive oxygen species

illustrate antioxidant activity (Valdivieso-Ugarte et al., 2019). Phenols contribute mainly because they have strong redox potential. These and others, like aldehydes, ketones, monoterpenes, alcohols, and ethers, cause disruption of peroxides and removal of free radicals (Amorati et al., 2013). The compounds involve menthone, isomenthone, thymus, linalool, citronellal, 1,8 cineole, carvacrol, α-terpinene, β- terpinene, α-terpinolene, cinnamon, neral, etc. show antioxidant activity**.** Double bonds present in compounds especially phenols are responsible for its mechanism of action. The process of oxidation consists of initiation, elongation, and termination steps. EOs break the chain of reaction either at the initiation or elongation stage. Both natural and synthetic EOs act as antioxidants (Salanță and Cropotova, 2022). The compounds obtained from thyme, oregano, mint, nutmeg, clove, basil, cinnamon, parsley, *etc.* are rich sources of oxygen and have great potential to act as antioxidants. Tocopherols, *Origanum compactum, Helichrysum italicum,* black cumin, sage, winter savory, wild thyme, basil, mint, clove, parsley, oregano, nutmeg, and retinol produce antioxidant effects (Jabeen et al., 2022).

Limitations to Essential Oils

Despite the huge advantages and applications of EOs, they also have some disadvantages. They can cause irritation (dermatitis), pneumonitis, photosensitivity, seizures, etc. Insufficient data is available that demonstrates the toxic risk of each EO. EOs as volatile oils, means are unstable. Being lipophilic in nature can damage cell membranes and make them more permeable (Barradas and de Holanda e Silva, 2021). Higher doses cause a reduction in the level of feed intake.

Future Prospects and Conclusion

There is a need for more studies that highlight the various mechanisms of action of EOs as antioxidant, immunomodulatory, and antiviral agents. Further studies are the need of time for the evaluation of the synergistic effects of various bioactive components of EOs, which may prove beneficial. In the future, more research may be done as there are many fields of EOs that require more advanced studies. Exploring EOs with others through conjugation may enable them to be the best preventive agents in the field of biology. EOs may be available as inflammatory drugs in the future. These EO-based drugs may be used as therapeutic drugs for treating infectious ailments. EOs, because of their enormous properties and popularity, are increasingly used in various fields to perform different functions. Multiple types of EOs due to the presence of bioactive components are explored in antiviral, immunomodulation, and antioxidant. They are industrially produced, and many are being commercialized. Phenolic EOs are very effective in producing the desired effects. They are safe to consume at recommended concentrations. Synergistic interactions can produce better results. EOs reduce the inflammation caused by disease mechanisms, boost the immune system against various viral diseases and improve health.

REFERENCES

Abdelli, I., Hassani, F., Bekkel Brikci, S., and Ghalem, S. (2021). In silico study the inhibition of angiotensin converting enzyme 2 receptor of COVID-19 by Ammoides verticillata components harvested from Western Algeria. *Journal of Biomolecular Structure and Dynamics*, *39*(9), 3263-3276. https://doi.org/https://doi.org/10.1080/07391102.2020.1763199

Akhand, A. A., and Ahsan, N. (2023). Cells and Organs of the Immune System. *Immunology for Dentistry*, 1-12. https://doi.org/ https://doi.org/10.1002/9781119893035.ch1

Amorati, R., Foti, M. C., and Valgimigli, L. (2013). Antioxidant activity of essential oils. *Journal of Agricultural and Food Chemistry*, *61*(46), 10835-10847. https://doi.org/https://doi.org/10.1021/jf403496k

Arsène, M. M. J., Davares, A. K. L., Viktorovna, P. I., Andreevna, S. L., Sarra, S., Khelifi, I., and Sergueïevna, D. M. (2022). The public health issue of antibiotic residues in food and feed: Causes, consequences, and potential solutions. *Veterinary World*, *15*(3), 662. https://doi.org/ 10.14202/vetworld.2022.662-671

Bakkali, F., Averbeck, S., Averbeck, D., and Idaomar, M. (2008). Biological effects of essential oils–a review. *Food and Chemical Toxicology*, *46*(2), 446-475. https://doi.org/https://doi.org/10.1016/j.fct.2007.09.106

Baldim, I., Souza, C. R. F., and Oliveira, W. P. (2021). Encapsulation of essential oils in lipid-based nanosystems. In *Phytotechnology* (pp. 197-230). CRC Press.

Baptista-Silva, S., Borges, S., Ramos, O. L., Pintado, M., and Sarmento, B. (2020). The progress of essential oils as potential therapeutic agents: A review. *Journal of Essential Oil Research*, *32*(4), 279-295. https://doi.org/https://doi.org/10.1080/10412905.2020.1746698

Barradas, T. N., and de Holanda e Silva, K. G. (2021). Nanoemulsions of essential oils to improve solubility, stability and permeability: a review. *Environmental Chemistry Letters*, *19*(2), 1153-1171.

Bhavaniramya, S., Vishnupriya, S., Al-Aboody, M. S., Vijayakumar, R., and Baskaran, D. (2019). Role of essential oils in food safety: Antimicrobial and antioxidant applications. *Grain and Oil Science and Technology*, *2*(2), 49-55. https://doi.org/https://doi.org/10.1016/j.gaost.2019.03.001

Brenner, D. M. (1993). Perilla: botany, uses and genetic resources. *CABI Digital Library*, 322-328.

Buckle, J. (2002). Clinical aromatherapy and AIDS. *Journal of the Association of Nurses in AIDS care*, *13*(3), 81-99. https://doi.org/https://doi.org/10.1177/10529002013003006

Chouhan, S., Sharma, K., and Guleria, S. (2017). Antimicrobial activity of some essential oils—present status and future perspectives. *Medicines*, *4*(3), 58. https://doi.org/10.3390/medicines4030058

Cimino, C., Maurel, O. M., Musumeci, T., Bonaccorso, A., Drago, F., Souto, E. M. B., and Carbone, C. (2021). Essential oils: Pharmaceutical applications and encapsulation strategies into lipid-based delivery systems. *Pharmaceutics*, *13*(3), 327. https://doi.org/https://doi.org/10.3390/pharmaceutics13030327

de Lavor, É. M., Fernandes, A. W. C., de Andrade Teles, R. B., Leal, A. E. B. P., de Oliveira Júnior, R. G., Gama e Silva, M., and Coutinho, H. D. M. (2018). Essential oils and their major compounds in the treatment of chronic inflammation: A review of antioxidant potential in preclinical studies and molecular mechanisms. *Oxidative Medicine and Cellular Longevity*, *2018*(1), 6468593. https://doi.org/https://doi.org/10.1155/2018/6468593

El Gendy, A. E.-N. G., Essa, A. F., El-Rashedy, A. A., Elgamal, A. M., Khalaf, D. D., Hassan, E. M., and Alamery, S. F. (2022). Antiviral potentialities of chemical characterized essential oils of Acacia nilotica bark and fruits against hepatitis A and herpes simplex viruses: In vitro, in silico, and molecular dynamics studies. *Plants*, *11*(21), 2889. https://doi.org/https://doi.org/10.3390/plants11212889

Grazul, M., Kwiatkowski, P., Hartman, K., Kilanowicz, A., and Sienkiewicz, M. (2023). How to naturally support the immune system in inflammation—Essential oils as immune boosters. *Biomedicines*, *11*(9), 2381. https://doi.org/https://doi.org/10.3390/biomedicines11092381

Guzmán, E., and Lucia, A. (2021). Essential oils and their individual components in cosmetic products. *Cosmetics*, *8*(4), 114. https://doi.org/https://doi.org/10.3390/cosmetics8040114

Hanif, M. A., Nisar, S., Khan, G. S., Mushtaq, Z., and Zubair, M. (2019). Essential oils. *Essential oil research: trends in biosynthesis, analytics, industrial applications and biotechnological production*, 3-17.

Jabeen, N. S., Kiruthiga, V., Vinodhini, A., and Rudrapal, M. (2022). Herbs, Spices, and Dietary Constituents as Sources of Phytoantioxidants. *Phytoantioxidants and Nanotherapeutics*, 55-76. https://doi.org/ https://doi.org/10.1002/9781119811794.ch3

Javed, H., Meeran, M. F. N., Jha, N. K., and Ojha, S. (2021). Carvacrol, a plant metabolite targeting viral protease (Mpro) and ACE2 in host cells can be a possible candidate for COVID-19. *Frontiers in Plant Science*, *11*, 601335. https://doi.org/https://doi.org/10.3389/fpls.2020.601335

Ju, J., Xie, Y., Yu, H., Guo, Y., Cheng, Y., Qian, H., and Yao, W. (2022). Synergistic interactions of plant essential oils with antimicrobial agents: A new antimicrobial therapy. *Critical Reviews in Food Science and Nutrition*, *62*(7), 1740-1751. https://doi.org/https://doi.org/10.1080/10408398.2020.1846494

Ma, L., and Yao, L. (2020). Antiviral effects of plant-derived essential oils and their components: an updated review. *Molecules*, *25*(11), 2627. https://doi.org/https://doi.org/10.3390/molecules25112627

Manion, C. R., and Widder, R. M. (2017). Essentials of essential oils. *American Journal of Health-System Pharmacy*, *74*(9), e153-e162. https://doi.org/https://doi.org/10.2146/ajhp151043

Mohammed, H. A., Sulaiman, G. M., Khan, R. A., Al-Saffar, A. Z., Mohsin, M. H., Albukhaty, S., and Ismail, A. (2024). Essential Oils Pharmacological Activity: Chemical Markers, Biogenesis, Plant Sources, and Commercial Products. *Process Biochemistry*, *144*, 112-132. https://doi.org/https://doi.org/10.1016/j.procbio.2024.05.021

Murbach Teles Andrade, B. F., Nunes Barbosa, L., da Silva Probst, I., and Fernandes Júnior, A. (2014). Antimicrobial activity of essential oils. *Journal of Essential Oil Research*, *26*(1), 34-40. https://doi.org/https://doi.org/10.1080/10412905.2013.860409

Mustafa, A., El-Kashef, D. H., Abdelwahab, M. F., Gomaa, A. A. R., Mustafa, M., Abdel-Wahab, N. M., and Ibrahim, A. H. (2023). Investigation of antiviral effects of essential oils. *Essential Oils: Extraction Methods and Applications*, 99-123. https://doi.org/https://doi.org/10.1002/9781119829614.ch5

Nadjib, B. M. (2020). Effective antiviral activity of essential oils and their characteristic terpenes against coronaviruses: An update. *Journal Pharmacology Clinical Toxicology*, *8*(1), 1138.

Oriola, A. O., and Oyedeji, A. O. (2022). Essential oils and their compounds as potential anti-influenza agents. *Molecules*, *27*(22), 7797. https://doi.org/https://doi.org/10.3390/molecules27227797

Pelvan, E., Karaoğlu, Ö., Fırat, E. Ö., Kalyon, K. B., Ros, E., and Alasalvar, C. (2022). Immunomodulatory effects of selected medicinal herbs and their essential oils: A comprehensive review. *Journal of Functional Foods*, *94*, 105108. https://doi.org/https://doi.org/10.1016/j.jff.2022.105108

Pérez-Santaescolástica, C., Munekata, P. E. S., Feng, X., Liu, Y., Bastianello Campagnol, P. C., and Lorenzo, J. M. (2022). Active edible coatings and films with Mediterranean herbs to improve food shelf-life. *Critical Reviews in Food Science and Nutrition*, *62*(9), 2391-2403. https://doi.org/https://doi.org/10.1080/10408398.2020.1853036

Peterfalvi, A., Miko, E., Nagy, T., Reger, B., Simon, D., Miseta, A., and Szereday, L. (2019). Much more than a pleasant scent: A review on essential oils supporting the immune system. *Molecules*, *24*(24), 4530. https://doi.org/https://doi.org/10.3390/ani12070823

Reichling, J. (2022). Antiviral and virucidal properties of essential oils and isolated compounds–a scientific approach. *Planta Medica*, *88*(08), 587-603. https://doi.org/10.1055/a-1382-2898

Rowland, E. (2024). *The Healing Power of Scent: A beginner's guide to the power of essential oils*. David and Charles.

Saad, N. Y., Muller, C. D., and Lobstein, A. (2013). Major bioactivities and mechanism of action of essential oils and their components. *Flavour and Fragrance Journal*, *28*(5), 269-279. https://doi.org/ https://doi.org/10.1002/ffj.3165

Sadgrove, N. J., Padilla-González, G. F., Leuner, O., Melnikovova, I., and Fernandez-Cusimamani, E. (2021). Pharmacology of natural volatiles and essential oils in food, therapy, and disease prophylaxis. *Frontiers in Pharmacology*, *12*, 740302. https://doi.org/https://doi.org/10.3389/fphar.2021.740302

Saini, R., and Dhiman, N. K. (2022). Natural anti-inflammatory and anti-allergy agents: herbs and botanical ingredients. *Anti-Inflammatory and Anti-Allergy Agents in Medicinal Chemistry (Formerly Current Medicinal Chemistry-Anti-Inflammatory and Anti-Allergy Agents)*, *21*(2), 90-114. https://doi.org/https://doi.org/10.2174/1871523021666220411111743

Salanță, L. C., and Cropotova, J. (2022). An update on effectiveness and practicability of plant essential oils in the food industry. *Plants*, *11*(19), 2488. https://doi.org/https://doi.org/10.3390/plants11192488

Sandner, G., Heckmann, M., and Weghuber, J. (2020). Immunomodulatory activities of selected essential oils. *Biomolecules*, *10*(8), 1139. https://doi.org/ https://doi.org/10.3390/biom10081139

Sarowska, J., Wojnicz, D., Jama-Kmiecik, A., Frej-Mądrzak, M., and Choroszy-Król, I. (2021). Antiviral potential of plants against noroviruses. *Molecules*, *26*(15), 4669. https://doi.org/https://doi.org/10.3390/molecules26154669

Sharifi-Rad, J., Salehi, B., Schnitzler, P., Ayatollahi, S. A., Kobarfard, F., Fathi, M., and Sharifi-Rad, M. (2017). Susceptibility of herpes simplex virus type 1 to monoterpenes thymol, carvacrol, p-cymene and essential oils of Sinapis arvensis L., Lallemantia royleana Benth. and Pulicaria vulgaris Gaertn. *Cellular and Molecular Biology*, *63*(8), 42-47. https://doi.org/https://doi.org/10.14715/cmb/2017.63.8.10

Sharma, A., Gumber, K., Gohain, A., Bhatia, T., Sohal, H. S., Mutreja, V., and Bhardwaj, G. (2023). Importance of essential oils and current trends in use of essential oils (aroma therapy, agrofood, and medicinal usage). In *Essential Oils* (pp. 53-83). Elsevier. https://doi.org/https://doi.org/10.1016/B978-0-323-91740-7.00002-5

Sharma, K., Mishra, V., Ranjan, K. R., Yadav, N., and Sharma, M. (2023). A Methodological Approach of Plant Essential Oils and their Isolated Bioactive Components for Antiviral Activities. *Essential Oils: Extraction Methods and Applications*, 1-29. https://doi.org/https://doi.org/10.1002/9781119829614.ch1

Sheng, Z., Jian, R., Xie, F., Chen, B., Zhang, K., Li, D., and Hu, L. (2020). Screening of larvicidal activity of 53 essential oils and their synergistic effect for the improvement of deltamethrin efficacy against Aedes albopictus. *Industrial Crops and Products*, *145*, 112131. https://doi.org/https://doi.org/10.1016/j.indcrop.2020.112131

Shikov, A. N., Mikhailovskaya, I. Y., Narkevich, I. A., Flisyuk, E. V., and Pozharitskaya, O. N. (2022). Methods of extraction of medicinal plants. In *Evidence-Based Validation of Herbal Medicine* (pp. 771-796). Elsevier. https://doi.org/https://doi.org/10.1016/B978-0-323-85542-6.00029-9

Singh, A., Anang, V., Kumari, K., Kottarath, S. K., and Verma, C. (2023). Role of lymphocytes, macrophages and immune receptors in suppression of tumor immunity. *Progress in Molecular Biology and Translational Science*, *194*, 269-310. https://doi.org/https://doi.org/10.1016/bs.pmbts.2022.10.002

Soleymani, S., Naghizadeh, A., Karimi, M., Zarei, A., Mardi, R., Kordafshari, G., and Zargaran, A. (2022). COVID-19: General strategies for herbal therapies. *Journal of Evidence-based Integrative Medicine*, *27*, 2515690X211053641.

Sosa, L., Espinoza, L. C., Valarezo, E., Bozal, N., Calpena, A., Fábrega, M.-J., and Mallandrich, M. (2023). Therapeutic applications of essential oils from native and cultivated ecuadorian plants: Cutaneous candidiasis and dermal anti-inflammatory activity. *Molecules*, *28*(15), 5903. https://doi.org/https://doi.org/10.3390/molecules28155903

Tirant, M., Tirant, H., and Wollina, U. (2024). Herbal Bioactive Compounds for Skin Infections and Inflammatory Conditions. *Open Access Macedonian Journal of Medical Sciences*, 247 - 290.

Valdivieso-Ugarte, M., Gomez-Llorente, C., Plaza-Díaz, J., and Gil, Á. (2019). Antimicrobial, antioxidant, and immunomodulatory properties of essential oils: A systematic review. *Nutrients*, *11*(11), 2786. https://doi.org/https://doi.org/10.3390/nu11112786

Vimalanathan, S., and Hudson, J. (2014). Anti-influenza virus activity of essential oils and vapors. *American Journal of Essential Oils and Natural Products*, *2*(1), 47-53.

Yingngam, B. (2022). Chemistry of Essential Oils. In *Flavors and Fragrances in Food Processing: Preparation and Characterization Methods* (Vol. 13(2023), pp. 189-223). ACS Publications.

Yousofi, A., Daneshmandi, S., Soleimani, N., Bagheri, K., and Karimi, M. H. (2012). Immunomodulatory effect of Parsley (Petroselinum crispum) essential oil on immune cells: mitogen-activated splenocytes and peritoneal macrophages. *Immunopharmacology and Immunotoxicology*, *34*(2), 303-308. https://doi.org/https://doi.org/10.3109/08923973.2011.603338

Zare, G., Diker, N. Y., and Çankaga, I. I. T. (xxxxx). Traditional Use of Medicinal Plants and Essential Oils. In *Essential Oils* (pp. 134-181). CRC Press.

Zhao, Q., Zhu, L., Wang, S., Gao, Y., and Jin, F. (2023). Molecular mechanism of the anti-inflammatory effects of plant essential oils: A systematic review. *Journal of Ethnopharmacology*, *301*, 115829. https://doi.org/https://doi.org/10.1016/j.jep.2022.115829

Zhu, B., Zhang, Q.-l., Hua, J.-w., Cheng, W.-l., and Qin, L.-p. (2018). The traditional uses, phytochemistry, and pharmacology of Atractylodes macrocephala Koidz.: A review. *Journal of Ethnopharmacology*, *226*, 143-167. https://doi.org/https://doi.org/10.1016/j.jep.2018.08.023

Zuo, X., Gu, Y., Wang, C., Zhang, J., Zhang, J., Wang, G., and Wang, F. (2020). A systematic review of the anti-inflammatory and immunomodulatory properties of 16 essential oils of herbs. *Evidence-Based Complementary and Alternative Medicine*, *2020*(1), 8878927. https://doi.org/ https://doi.org/10.1155/2020/8878927