

**SCIENTIFIC INSIGHTS INTO VAPOR PHASE ESSENTIAL OILS AND THEIR
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ABSTRACT

The volatile part of essential oils extracted from plants, when dispersed throughout the atmosphere, is known as the vapour phase essential oils, allowing them to interact with microorganisms in the air and the human respiratory tract. The use of vapor phase delivery has gained considerable momentum in recent years because of its superior antimicrobial activity and non-invasive application, in addition to the possibility of using it in the food area, clinical settings and the management of indoor air quality. This review includes detailed information about the chemistry, mechanism of action, antimicrobial and therapeutic applications, drawbacks and future research avenues for vapor phase essential oils. They have been highlighted with regard to the latest scientific data regarding their effectiveness against bacteria, fungi and viruses. Also, the issues of regulation and toxicity and the need for standardization are discussed. The purpose of this article is to give a scientific basis for future research and application.

KEYWORDS: Essential oils-vapor phase, volatile compounds, antimicrobial activity, aromatherapy, air disinfection, food preservation.

INTRODUCTION

Essential oils (EOs) are complex, volatile, aromatic, naturally occurring mixtures from many plant parts – leaves, flowers, bark, roots, seeds, fruits and peels. The oils are usually extracted by steam distillation, hydrodistillation, solvent extraction or cold pressing depending on the plant material.^[1] Essential oils are known to contain several bioactive compounds such as terpenes, terpenoids, phenols, aldehydes, alcohols, ketones, esters and ethers which are responsible for their fragrance and different properties.^[2] The ability of essential oils to act as therapeutic agents and their pleasing aroma have made them popular in traditional medicine, perfumery, cosmetics, aromatherapy, food preservations and pharmaceutical preparations since ancient times.^[3] The emergence of problems related to antimicrobial resistance, pollution and side effects of synthetic preservation agents have led to a large number

of studies on natural bioactive compounds, mainly essential oils.^[4] The indiscriminate and overuse of antibiotics has led to the development of microorganisms that are multi-drug resistant, posing a huge public health threat. Hence, scientists are keen on finding out new plant-based volatile compounds as alternative antimicrobial agents that are safer and environmentally friendly.^[5] Essential oils possess antimicrobial, antioxidant, antiviral, antifungal, anti-inflammatory and insecticidal properties and these are considered as promising candidates.^[6] The biological activity of the volatile essential oils is the main reason for their volatile nature and synergistic effect of the chemical components.^[7] Essential oils tend to have several modes of action as compared to synthetic antimicrobial agents, which means there is a lower likelihood for resistance to occur among the microorganisms.^[8] The gaseous form of the volatile constituents of an essential oil that has been

vaporized is called essential oils in the vapor phase. The vapor phase application has received scientific interest because of its ability to provide a better dispersion and/or distribution of the active molecules in confined spaces.^[9] Vapor phase exposure results in higher contact with microorganisms and less residue than liquid application.^[10] A few investigations have revealed antimicrobial activity of vapours more effective than liquids because of better diffusion and penetration.^[11] The efficacy of the fumes of essential oil against pathogenic bacteria, fungi like *Staphylococcus aureus*, *Escherichia coli*, *Pseudomonas aeruginosa*, *Candida albicans* and *Aspergillus* species has been investigated.^[12] Essential oils have also been found to exhibit potent properties in the preservation of food systems and their ability to inhibit the growth of microorganisms associated with food spoilage.^[13] In addition, essential oils can be used to successfully reduce the levels of microorganisms in the indoor environment of health care and domestic settings.^[14] The essential oils in the vapour phase are widely employed in aromatherapy and respiratory therapy, and lead to relaxation, decongestion and better respiratory function when inhaled.^[15] The other commonly used oils for inhalation therapy are eucalyptus, peppermint, lavender and tea tree oils for their therapeutic benefits.^[16] The effectiveness of their use is related to composition, volatility, exposure time and environmental conditions.^[17]

Chemical Composition and Bioactive Constituents

Essential oils are secondary metabolites of aromatic plants and they are volatile substances which depend on geographical, climatic and extraction technique.^[18] They have 20-60 constituents, some of which are dominant bioactive compounds that cause biological activity.^[19] They fall in to three categories: terpenes, terpenoids and phenylpropanoids.^[20] Monoterpenes like limonene, α -pinene and myrcene have an aroma and antimicrobial properties, whereas sesquiterpenes such as β -caryophyllene have anti-inflammatory and antimicrobial properties. The antimicrobial activity is higher for oxygenated terpenoids like linalool and menthol, which are able to interact with the membranes.^[23] Thymol, carvacrol and eugenol are highly active antimicrobial agents.^[24] which are phenolic compounds. Some aromatic compounds, such as cinnamaldehyde, are biologically active.^[25] Whole oils are more effective than isolated components due to synergistic interactions between components that increase antimicrobial activity.^[26] The essential oils have many biological activities and are widely used in pharmaceuticals, food preservation, cosmetics and agriculture.^[27]

Volatility and Vaporization

Volatility is a property that varies with vapor pressure, molecular weight, temperature and environment.^[28] Monoterpenes are very volatile and are the most active of the vapors.^[29] With higher temperatures, evaporation and diffusion of volatile compounds is promoted.^[30] Vapor

phase essential oils are capable of achieving uniform air distribution and contact with airborne microbes.^[31]

Mechanism of Antimicrobial Action

The essential oil vapors operate by interacting with the cell wall of the microorganisms because they are lipophilic.^[32] This results in intracellular components leakage and cell death.^[33] Gram-negative bacteria are more resistant than Gram-positive bacteria as a result of differences in the cell wall structure.^[34] Essential oils are also able to inhibit enzyme systems and metabolic pathways like ATP synthesis and electron transport.^[35] These can generate reactive oxygen species (ROS) and cause damage to the cells.^[36]

Antimicrobial Activity of Vapor Phase Essential Oils

Vapor phase essential oils possess the highest antimicrobial, antifungal and antiviral properties as they are able to diffuse in the air and interact with microbial surfaces.^[13] These will work better than liquids because they penetrate and diffuse better.^[14] They can effectively combat *E. coli*, *Salmonella*, *Listeria monocytogenes* and *Staphylococcus aureus*.^[12] which are foodborne pathogens. Activity against *Aspergillus* spp., *Penicillium* spp. and *Candida* spp. are noted as antifungal activity.^[29] Mechanisms include membrane disruption, enzyme inhibition and ergosterol synthesis inhibition.^[24]

APPLICATIONS

Vapor Phase Essential Oils are extensively used in aromatherapy for stress reduction, relaxation and respiratory support.^[16] They are used for air disinfection in hospitals, offices and households to decrease the amount of microbes.^[14] They are used in food packaging to prevent microbes growth and prolong the shelf life of food.^[13] They are also employed in agriculture to protect against pests and after harvest.

ADVANTAGES

Benefits include wide-spectrum antimicrobial activity, using an environmentally friendly method, biodegradability and non-invasive application.^[14]

LIMITATIONS AND CHALLENGES

Some constraints are volatility, chemical variability, lack of standardization and potential toxicity at high exposure level.^[6] To tackle these problems, nano-encapsulation and smart packaging are being developed.^[35] Combination therapy with antibiotics is more effective, and less likely to lead to resistance.

Future Perspectives

Further studies should concentrate on clinical validation, formulation and standardisation for safe usage.^[35] The antimicrobial, therapeutic and environmental uses of the vapor phase essential oils are perceived as a powerful and natural alternative.

CONCLUSION

Vapor phase essential oils are a potential natural solution for antimicrobial, therapeutic, environmental and food preservation uses. The biological activities are mainly reported to be associated with volatile bioactive compounds, including terpenes, terpenoids and phenolic compounds, that possess strong antibacterial, antifungal, antiviral, antioxidant and anti-inflammatory properties. Some of the advantages of vapor phase application are: non-invasive application, uniform air distribution, better vaporisation and improved diffusion, less requirement for direct contact and eco-friendly properties. Due to these properties, vapored essential oils are well suited for use in air disinfection, respiratory therapy, active food packaging and agricultural preservation systems. The antimicrobial effect of essential oil vapour is attributed to several mechanisms including disruption of microbial cell membrane, inhibition of metabolic enzymes, induction of oxidative stress and synergistic effect of volatile compounds of the essential oil. They have been shown in numerous studies to be effective against a variety of pathogenic bacteria, fungi, and even some enveloped viruses. Moreover, the development of nanotechnology (nanoshells, nanospheres, and nanoemulsions) and smart packaging systems, along with combination therapies, have further improved the stability, activity, and controlled release of essential oil vapors. The challenges such as high volatility, variability of chemical composition, safety concerns, and the absence of standardized regulatory guidelines, still prevent their large-scale applications despite their tremendous potential. Thus, additional studies with clinical validation, toxicology testing, formulation standardization, and the development of advanced delivery systems are required to guarantee safe, effective and sustainable use of the vapor phase essential oils in pharmaceutical, food, agricultural and environmental applications.

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Conflict of Interest

None.

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