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Review

Antibacterial potential of essential oils from medicinal plants for food preservation: a review

[Potencial antibacteriano de los aceites esenciales de plantas medicinales
para la conservación de alimentos: una revision]

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Abstract: Essential oils, also called volatile or ethereal oils, are compounds naturally present in plants. Several medicinal plants are sources of these essential oils extraction, besides different secondary metabolites that are produced, such as terpenoids, alcoholic compounds, aldehydes, ketone bodies and phenols. The essential oils usage as substitutes for synthetic preservatives in food has been gaining space in research due to the interest of the population in consuming healthier products. Moreover, the industry seeks to attend the necessities of the consumers to produce foods with less synthetic additives, but ensuring the preservation of organoleptic characteristics and shelf life. This review aims to present the antibacterial activity of essential oils from medicinal plants and its use as a food preservative.

Keywords: Food pathogens; Preservatives; Foodborne diseases; Volatile oils.

Resumen: Los aceites esenciales, también llamados aceites volátiles o etéreos, son compuestos presentes de forma natural en las plantas. Varias plantas medicinales son fuente de extracción de estos aceites esenciales, además de diferentes metabolitos secundarios que se producen, como terpenoides, compuestos alcohólicos, aldehídos, cuerpos cetónicos y fenoles. El uso de aceites esenciales como sustitutos de conservantes sintéticos en los alimentos ha ido ganando espacio en la investigación debido al interés de la población por consumir productos más saludables. Además, la industria busca satisfacer las necesidades de los consumidores de producir alimentos con menos aditivos artificiales, pero asegurando la preservación de las características organolépticas y la vida útil. Esta revisión tiene como objetivo presentar la actividad antibacteriana de los aceites esenciales de plantas medicinales y su uso como conservante de alimentos.

Palabras clave: Patógenos alimentarios; Conservantes; Enfermedades transmitidas por alimentos; Aceites volátiles.

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INTRODUCTION

Pathogenic and spoilage microorganisms are naturally present in the environment and can contaminate food at different stages of the production chain, for example, during harvesting, slaughter, processing and/or packaging (Hatab *et al*., 2016). World food losses can reach 40% a year, due to numerous factors, including spoilage caused by microorganisms (Gustavsson *et al*., 2011). Microbial spoilage can be caused by bacteria, molds and yeasts (Lianou *et al*., 2016), as it uses available nutrients and produces metabolites, which largely affect the sensory and nutritional characteristics of foods (Parlapani *et al*., 2017).

Contaminant pathogenic microorganisms in food processing can produce toxins that cause harmful effects on human health (Chen *et al*., 2020). Foods of animal origin were reported as the main carriers of food pathogens, being: eggs, meat by-products, pork, poultry, fish, milk, dairy products, beef and shellfish (EFSA, 2016). The principal associated bacteria are *Bacillus cereus*, *Campylobacter jejuni*, *Clostridium botulinum*, *Clostridium perfringens*, *Cronobacter sakazakii*, *Escherichia coli*, *Listeria monocytogenes*, *Salmonella* spp., *Shigella* spp. and *Staphylococcus aureus* (Bintsis, 2017), which can cause foodborne illness.

Foodborne illnesses caused through the contaminated food consumption by microorganisms is a challenge to food safety and public health. Every year, around 600 million people in the world sicken and 420.000 die from ingesting contaminated food, mainly by bacteria (FAO, 2019). These diseases undermine socioeconomic development, burdening health systems, as well as the world economy and trade (FAO, 2019). Estimates indicate that the impact of unsafe food generates productivity losses of around US$95 billion per year in low- and middle-income economies (FAO, 2019).

Antibiotic resistance within food production is a concern for public health, as its indiscriminate use in treatment of human and animal health has become an important influence on the emergence and persistence of resistant strains. According to the US Centers for Disease Control and Prevention, approximately 2 million people are infected with multidrug-resistant (MDR) bacteria annually, averaging 23.000 deaths (Cheng *et al*., 2019). Because of these factors, the use of natural compounds obtained from aromatic and medicinal plants has become an alternative to control food pathogens, and can be used as preservatives, hence ensuring food quality (Gebreyes *et al*., 2017).

Consistent with the National Health Surveillance Agency, preservatives can be considered as additives, that is, any and all ingredients intentionally added to foods without the purpose of nourishing, with the objective of modifying the physical, chemical, biological or sensory characteristics, during manufacture, processing, preparation, treatment, packaging, conditioning and storage (Brasil, 1997). Synthetic antimicrobial preservatives are used in order to extend the foods shelf life, but it can cause toxic effects on individuals exposed through food consumption, depending on the amount ingested and the susceptibility of the human body. In indiscriminate amounts, preservatives can cause the following health problems: benzoic acid (asthma), sorbic acid (hives, asthma and allergy), sulfur dioxide (toxicological effects and respiratory problems), sulfites (allergies, hypotension, nausea, gastric irritation, hyperactivity, diarrhea, asthma attacks and urticaria), nitrites and nitrates generates methemoglobinemia, which, in addition to being carcinogenic, can cause increased blood pressure, heart disease, vasodilator action, headache and gastrointestinal discomfort (Conte, 2016; Bensid *et al*., 2020).

Considering the occurrence of antimicrobial resistance and possible diseases caused by the use of synthetic preservatives, studies with the addition of natural substances, such as essential oils in foods have been developed. Essential oils, also called volatile or ethereal oils, are compounds naturally present in plants and have functions related to its defense mechanisms. The essential oil content in the plant can be associated with several factors, for example: temperature, luminosity, seasonality, plant development stage, harvest time and plant nutrition. Essential oil are oily aromatic liquids, characterized by intensive flavor and smell, and can be obtained from plant material, such as flowers, shoots, seeds, leaves, branches, bark, wood, fruits and roots (Morais, 2009; Dhifi *et al*., 2016). The use of essential oils as a substitute for synthetic preservatives in food is of great interest to the industry, which seeks to attend the needs of its consumers, aiming to produce food with fewer artificial additives, but ensuring the maintenance of the sensory characteristics and safety of the product. (Tajkarimi *et al*., 2010). This review article is focused on the potential antibacterial activity of essential oils from medicinal plants and its utilization as food preservatives. Aspects, such as chemical composition, antimicrobial activities, as current application of essential oil from medicinal plants in food matrices, have been discussed.

METHODOLOGY

In the present study, the narrative bibliographical review was carried out using the databases Science Direct, Scopus and Scielo platforms, as scientific databases. The keywords used as descriptors were: "essential oils", "medicinal plants essential oil", "food preservative", "antibacterial", as a search strategy. Articles published during the period from 2018 to 2021 were selected. Articles from previous years were maintained in the base of the article, once the information reported was considered of importance for the general discussion.

Chemical composition and antibacterial activity of essential oils from medicinal plants

Essential oils are constituted by a complex mixture of polar and non-polar substances (Raut & Karuppayil, 2014), which different secondary metabolites can be present as terpenes (monoterpenes and sesquiterpenes), aromatic compounds (aldehyde, alcohol, phenol, methoxy derivative, etc.), and terpenoids (isoprenoids) (Bakkali *et al*., 2008). Essential oils have exhibited promising antimicrobial action against several microbial species (Ribeiro-Santos *et al*., 2018). Table No. 1 compiles the essential oils of some medicinal plants species, major chemical compounds and the minimum inhibitory concentration (MIC) against the principal pathogenic bacteria of interest in foods. The chemical compounds that constitute essential oils can vary according to the plant species and the plant part used for extraction, such as branches, leaves, flowers, seeds, rhizomes and fruits (Edris, 2007). Furthermore, the chemical composition may vary depending on climatic conditions, harvest time, geographic region, cultivation method, soil and maturation stage (Dhifi *et al*., 2016; Ribeiro-Santos *et al*., 2018; Li *et al*., 2020), and all these factors can influence the antibacterial activity.

The action mechanism of the antibacterial activity of essential oils has not yet been completely elucidated (Calo *et al*., 2015). Gram-positive bacteria are generally more susceptible to essential oils than Gram-negative bacteria (Nazzaro *et al*., 2013), because the complexity of the its cell wall constitution, such as the presence of lipopolysaccharide, that hinders the essential oil penetration into the cell (Nazzaro *et al*., 2013). Since it is constituent of several biomolecules, the antimicrobial activity of essential oils cannot be confirmed based on a single mode of action (Bajpai *et al*., 2012). The action can be attributed to the ability to penetrate the bacterial cell membrane and inhibit its functioning properties (Bajpai *et al*., 2012).

The antibacterial action of essential oils may be linked to the major phenolic compounds presence, such as thymol, carvacrol and eugenol, however, studies have demonstrated that other compounds present in smaller amounts that act in synergism, altering the permeability of the bacterial cell membrane, causes death (Rattanachaikunsopon & Phumkhachorn, 2010; Adelakun *et al*., 2016). The oregano essential oil, which has carvacrol and *p*-cymene, as major, can cause irreversible damage to the cell membrane of MRSA *S. aureus*, inhibit the tricarboxylic acid cycle pathway and its main enzymes, as well as inhibit the expression of the pvl gene; in addition, the major compound carvacrol can form chimera with DNA (Cui *et al*., 2019). Ginger essential oil, which is mainly zingiberene and α-curcumene, can inhibit the expression of some genes related to energy metabolism, tricarboxylic acid cycle, cell membrane-related proteins and DNA metabolism in *E. coli* and *S. aureus* (Wang *et al*., 2020).

Studies have related the combined action of the compounds carvacrol and thymol in the disintegration of the outer membrane present in the wall of Gram-negative bacteria, releasing lipopolysaccharides and increasing the permeability of the cytoplasmic membrane to ATP (Helander *et al*., 1998; Lambert *et al*., 2001; Burt, 2004). Eugenol promotes cell wall degradation and cell lysis (Thoroski *et al*., 1989). P-cymene, the carvacrol precursor, has high affinity for the membranes of microorganisms, due to the benzene ring in the chemical structure, which can disturb the cell membrane potential and cause swelling of the cytoplasmic membrane (Ultee *et al*., 2002). Terpinen-4-ol promotes inhibition of oxidative respiration, inducing membrane deformation, causing changes in membrane permeability (Cox *et al*., 2000).

Table No. 1

Chemical composition and minimum inhibitory concentration (MIC) of essential oils from some medicinal plants species *in vitro* on pathogenic bacteria of interest in food

Plant	Major compounds	Bacterium and MIC (mg/mL)	Reference
Origanum vulgare	Carvacrol (64,86%) *ρ*-Cymene (8.354%)	*Staphylococcus aureus* - MRSA (0.4)	Cui *et al*., 2019
Cinnamomum camphora (Linn.)	Linalool (26.6%) eucalyptol (16.8%) α-terpineol (8.7%), isoborneol (8.1%) β-phellandrene (5.1%) camphor (5.0%)	*Staphylococcus aureus* (1.6) *Bacillus subtilis* (1.6) *Enterococcus faecalis* (1.6) *Escherichia coli* (3.2) *Salmonella gallinarum* (1.6)	Chen *et al*., 2020
Psidium cattleianum (leaves)	β-caryophyllene (14.7%) 1,8-cineole (11.7%) ɣ-muurolene (5.6%)	*Bacillus cereus* (1.40) *Pseudomonas aeruginosa* (1.40) *Staphylococcus aureus* (2.10) *Salmonella enterica* (5.62)	Salvoldi *et al*., 2020
Myrcianthes pungens (leaves)	β-caryophyllene (11.7%) 1,8-cineole (10.1%)	*Staphylococcus aureus* (0.078) *Bacillus cereus* (0.42)	De Jesus *et al*., 2021
Baccharis coridifolia	Germacrene-D (23.7%), bicyclogermacrene (17.1%) (E)-caryophyllene (8.4%)	*Pseudomonas aeruginosa* (0.51) *Staphylococcus aureus* (0,128)	Freitas *et al*., 2020
Cinnamom cassia	E-cinnamaldehyde (76.54%)	*Listeria monocytogenes* (0.1)	Somrani *et al*., 2020
Zingiber officinale	Zingiberene (35.65%) α-Curcumene (12.04%)	*Staphylococcus aureus* (1.0)	Wang *et al*., 2020
Rosmarinus officinalis L.	1,8-cineole (17.16 %) α-pinene (16.95 %)	*Staphylococcus aureus* (0.06)	Mohammed *et al*., 2020
Litsea cubeba	β-Citral (39.25%) α-Citral (30.89%) Limonene (8.28%)	*Escherichia coli* O157:H7 (0.5)	Dai *et al*., 2021
Laurus nobilis L. (leaves)	1.8-cineol (41.1 %) sabinene (6.96 %) α-pinene (5.94 %) humulene epoxide II (5.73 %) α-terpinenyl acetate (5.72 %)	*Escherichia coli* O157:H7 (0.75) *Staphylococcus aureus* (0.75) *Listeria monocytogenes* (0.37) *Bacillus cereus* (0.75)	Tomar *et al*., 2020
Syzygium aromaticum, L.	Eugenol (56.06%) caryophyllene (39.63%) α-caryophyllene (4.31%)	*Staphylococcus aureus* (0.30) *Escherichia coli* (0.30) *Listeria monocytogenes* (0.30) *Salmonella typhimurium* (0.30)	Radünz *et al*., 2019
Satureja khuzestanica	Carvacrol (87.16%) *p*-cymene (6.39%)	*Escherichia coli* (0.25) *Staphylococcus aureus* (0.25) *Salmonella enterica* (0.25)	Mazarei & Rafati, 2019

Applications of essential oils from medicinal plants in food

Essential oils are of growing interest due to the population's demands from consumers for natural foods. Several studies with the application of essential oils from medicinal plants are reported in Table No. 2, aiming at the control of pathogenic bacteria in different food matrices. *Litsea cubeba* essential oil was tested in bitter gourd, cucumber, carrots and spinach juices at 4°C (common storage temperature for fresh juices) and in MIC concentration (0.5 mg/mL), the viable count of *E. coli* O157:H7 in four samples decreased above 99% after 4 days storage (Dai *et al*., 2021). Radünz *et al*. (2019), showed that clove essential oil inhibited the growth of *S. aureus* in burger-like meat more efficiently than the preservative nitrite. Šojić *et al*. (2018), showed that the addition of 0.1 μL/g of *Salvia officinalis* essential oil in fresh pork sausage contributed to a reduction from 7.66 log cfu/g (control) to 7.0 log/cfu g of total mesophilic aerobic count after 8 days storage. Ksouda *et al*. (2019), reported that the presence of 3% of *Pimpinella saxifraga* essential oil in cheese coating reduced the proliferation of mesophilic bacteria from 5.44 to 4.03 log CFU/g at day 7 of chilled storage. Sahin & Kilic (2021), evaluated the antimicrobial capacity of some essential oils, obtaining more effective results through the *Thymus vulgaris* essential oil, which presented zones of inhibition of 49.27 ± 7.26 mm against *S. aureus*, 44.13 ± 4.16 mm against *L. monocytogenes*, 39.55 ± 0.52 mm against *E. coli* and 38.09 ± 4.15 mm against *M. luteus*. The chromatography performed by the authors presented thymol, carvacrol, caryophyllene, 1,8-cineole, 2-acetyl-4,5-dimethylphenol and γ-terpinene in the composition of *T. vulgaris*.

An important factor in the application of a substance in a food system is the medium homogeneity used in preliminary in vitro tests, which in liquid or in gel culture medium can be more effective; on the other hand, once applied to foods, the effectiveness will depend on the matrix composition, which can be complex or heterogeneous (Weiss *et al*., 2015). Because of the possibility of interacting with food components, high concentrations may be necessary to achieve the same efficacy in comparison to the in vitro tests (Aloui & Khwaldia, 2016). Therefore, detailed studies of the antimicrobial properties of essential oils, such as MIC, action mode and target microorganism, in addition to the interaction with food components, are necessary for application as biopreservatives to control microorganisms in food systems (Hyldgaard *et al*., 2012).

Factors inherent to foods also influence the antimicrobial activity of essential oils after applied to food matrices, such as chemical composition, pH, water activity, temperature and storage atmosphere. Low pH values can contribute to increase the solubility and stability of the essential oils (Burt, 2004). High concentration of proteins or fats in food composition can provide a protective layer around the microorganism or absorb the antimicrobial substance, consequently, reducing its concentration and effectiveness in aqueous medium (Tyagi *et al*., 2012; Perricone *et al*., 2015). Thyme and cinnamon essential oils were more effective against *Salmonella* in hydrated tahini (water activity of 0.96) than non-hydrated (water activity of 0.25), as the hydration provided dilution and reduced the fat content available in the product (Al-Nabulsi *et al*., 2020).

The combination of essential oils from different plant species can increase the spectrum of antimicrobial action through synergism. Diniz-Silva *et al*. (2019), showed that essential oils from *Origanum vulgare L.* (0.03 μL/g) and *Rosmarinus officinalis L.* (1.32 μL/g) had a synergistic effect against *E. coli* O157:H7 in fresh cheese. The terpene content decreased during the fresh cheese storage, and the non-detection of y-terpinene and carvacrol after 3 days of storage may be related to its solubility and volatility, as well as to its ability to react with proteins and fat (Diniz-Silva *et al*., 2019).

Likewise, the use of essential oils incorporated in polymeric matrices is a well-studied method, which provides good food preservation results. Raeisi *et al*. (2020), produced nanofiber coatings from isolated soybean protein and gelatin, incorporated with essential oil of *Zataria multifora* and *Cinnamon zeylanicum*. The authors reported the biofilm incorporated with 20% of *Z. multifora* reduced 100% the action of *S. aureus*, *B. cereus* and *L. monocytogenes* and the reduction against *E. coli* was 70%, and 63% for *S. typhimurium*.

Challenges and perspectives for essential oils application in food

As a natural origin compound, essential oils have become an attraction for population and industries, in the search for alternatives to develop healthier and quality products (Tajkarimi *et al*., 2010). Nevertheless, despite the effectiveness of the antibacterial potential of essential oils for application in food matrix, detailed studies are necessary to promote the desired antimicrobial effect, without changing the sensory characteristics of the food, since in many cases the required inhibitory concentration is greater than the determined in vitro assays (Bhavaniramya *et al*., 2019; Falleh *et al*., 2020), thus impairing the final flavor of the product.

In addition to sensory alterations due to its intense flavor, essential oils can be affected by stability at high temperatures, light and oxygen, consequently, limiting the use as natural preservatives (Zhu *et al*., 2021). Radunz *et al*. (2020), studied *Thymus vulgaris* essential oil microencapsulated in casein-maltodextrin capsules produced by spray-drying and found that encapsulated was more effective than non-encapsulated in preserving hamburger-like products against *E. coli*. They obtained an antimicrobial effect up to 14 days of storage due to the slow release of volatile compounds, which were protected by encapsulation, and the results were similar to the synthetic additive nitrite (Radünz *et al*., 2020). Froiio *et al*. (2019), mentioned that the essential oils incorporation in polymeric matrix is a manner to protect it from degradation, make it soluble to be incorporated in aqueous environment, camouflage its strong aroma and avoid its interaction with others food components. However, this method still needs economic and process adjustments to be feasible on industrial scales. Therefore, it is noted that as effective as essential oils are, it is still necessary to establish a methodology that enables its usage in industry.

Table No. 2
Application of essential oils from medicinal plants as antibacterial in different food matrix

Plant	Major compounds	Food matrix	Microorganism	Reference
Litsea cubeba	β-Citral (39.25%) α-Citral (30.89%) Limonene (8.28%)	Vegetable juices	*E. coli* O157:H7	Dai *et al.*, 2021
Syzygium aromaticum L.	Eugenol (56.06%), Caryophyllene (39.63%) α-caryophyllene (4.31%)	burger-like meat	*S. aureus*	Radünz *et al*., 2019
Cinnamon	-	Tahini	*Salmonella* spp.	Al-Nabulsi *et al.*, 2020
Salvia officinalis L.	Epirosmanol (26.25%), Viridiflorol (18.42%) Camphor (12.74%)	Fresh pork sausage	Total mesophilic aerobic count	Šojić *et al*., 2018
Zingiber officinale	α-zingiberene (24.96%) β-sesquiphellandrene (12.74%)	Coating emulsão in chicken breast fillets	Psychrophilic bacteria	Noori *et al.*, 2018
Pimpinella saxifraga	Anethole (59.47%) Pseudoisoeugenol (20.15%)	Sicilian cheese	Mesophilic bacteria	Ksouda *et al.*, 2019
Pimpinella anisum	Anethole (80.84%) Piperitenone oxide (5.76%) *p*-Allylanisole (2.9%) Acetisoeugenol (2.05%) *trans*-Caryophyllene (2.05%)	Minced beef	*Pseudomonas* spp.	Khanjari *et al.*, 2018
Origanum vulgare L. *Rosmarinus officinalis L.*	Origanum: Thymol ρ-cymene Carvacrol γ-terpinene Rosmarinus: Eucalyptol Camphor α-pinene Caryophyllene Camphene	Fresh cheese	*Escherichia coli* O157:H7	Diniz-Silva *et al.*, 2019

CONCLUSION

Essential oils from medicinal plants exhibit potential against pathogenic and spoilage bacteria of interest in foods. Essential oils are promising alternatives for replacing synthetic preservatives used in the food industry. Overall, essential oils application in food is a challenge that requires further studies and improvement of techniques so barriers, such as flavor alterations and substance oxidation, making its usage and acceptability viable.

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