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Essential oils in Food Systems: A systemic review

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Abstract : Many consumers are demanding foods without what they perceive as artificial and harmful chemicals, including many used as antimicrobials and preservatives in food. Consequently, interest in more natural, non-synthesized, antimicrobials as potential alternatives to conventional antimicrobials to extend shelf life and combat foodborne pathogens has heightened. Aromatic plants and their components have been examined as potential inhibitors of bacterial growth and most of their properties have been linked to essential oils and other secondary plant metabolites. Historically, essential oils from different sources have been widely promoted for their potential antimicrobial capabilities. The essential or volatile oils are extracted from the flowers, barks, stem, leaves, roots, fruits and other parts of the plant by various methods. It came into existence after the scientists deciphered the antiseptic and skin permeability properties of essential oils.
Key words: Essential oil, Antimicrobial, Chemistry, Biological properties.

1. Introduction

Essential oils (EOs) have gained a renewed interest in several areas. As natural products, they have interesting physicochemical characteristics with high added values respecting the environment. EOs also have diverse and relevant biological activities. For instance, they are used in the medical field thanks to their biocidal activities (bactericidal, virucidal and fungicidal) and medicinal properties. Numerous studies have highlighted EOs antimicrobial effects even against multi-resistant bacteria[1]. Furthermore, EOs have been used against nosocomial infections, as a cleaning liquid for disinfection of medical equipment and surfaces[2] or as an aerosol in operating blocks and waiting rooms for air cleaning to limit contaminations[3]. They could also provide a pleasant feeling of psychic comfort for patients thanks to their pleasant odor. Use of EOs as food preservatives has also been described[4]. Because of their complex chemical composition, often composed of more than 100 different terpenic compounds, EOs have a broad biological and antimicrobial activity spectrum (antibacterial, antifungal, antimoulds, antiviral, pest control, insect repellents). In the pharmaceutical field, EOs are included in the composition of many dosage forms (capsules, ointments, creams, syrups, suppositories, aerosols and sprays). Preparations' number is constantly growing. They are intended mainly of local applications as mixtures with vegetable oils or inhalation.

Food industry also presents a growing demand for Eos because of their important applications as food preservatives[5], innovation in food packaging and the fight against pathogens generating dangerous food poisoning (Listeria monocytogenes, Salmonella typhimurium, Clostridium perfringens, Pseudomonas putida and staphylococcus aureus). Numerous studies have demonstrated the efficiency of EOs in low doses in the fight against bacterial pathogens encountered in food industry and meat product[6]. Likely, there was an increased public concern about the use of antibiotics in livestock feed because the emergence of antibiotic resistant bacteria and their possible transmission from livestock's to humans. In fact, in the European Union, use of synthetic antibiotics, health and growth promoters as additives in livestock feed has been prohibited since 2006[7].

In this context, EOs were shown to be an interesting alternative because of their well- known and well documented antimicrobial activity. EOs contain components with biocide and antiviral properties that can be used as substitutes of synthetic drugs in livestock[8]. The Food and Drug Administration recognized EOs as safe substances according to Code of Federal Regulations and some contain compounds can be used as antibacterial additives[9]. In this review we will discuss mechanisms of antimicrobial action and the antimicrobial properties of plant EOs, effectiveness in foods and synergistic or antagonistic effects for use in food systems.

2. Essential oils

Ethnobotany is an approach to gain knowledge about traditional uses of medicinal plants[10,11]. These naturally occurring antimicrobials have extensive histories of their use in foods and can be identified from various components of the plants leaves, barks, stems, roots, flowers and fruits[12]. Essential oils are not strictly oils, but are often poorly soluble in water as are oils. Essential oils often have a pleasant odor and sometimes a distinctive taste and are therefore used in significant amounts in the flavoring and perfume industries[5]. Essential oils are usually prepared by fragrance extraction techniques such as distillation (including steam distillation), cold pressing, or extraction (maceration)[13]. Typically, EOs are highly complex mixtures of often hundreds of individual aroma compounds. Herbs and spices commonly used in foods have provided most of the EOs that have been studied for their antimicrobial activity[14].

3. Properties of essential oils

The antimicrobial or other biological activities of EOs are directly correlated to the presence of their bioactive volatile components[15]. Chemically the EOs consist of terpene compounds (mono-, sesqui- and diterpenes), alcohols, acids, esters, epoxides, aldehydes, ketones, amines and sulfides[16]. The components of EOs can be divided into two groups: (i) terpene compounds and (ii) aroma compounds[16]. Composition of the EOs of any particular plant can be dependent on what part of the plant is used: flowers, green parts (leaves and stems), bark, wood, whole fruits, pericarp or seed only, or roots[17]. Kuropka, Neugebauer & Glombitza (1991) demonstrated that in *Achillea ptarmica* the mono-terpenes were found in very small amounts in oils from the green parts and roots, while high levels were found in EOs from the flowers. Essential oils are thought to be produced by plants in response to stressors and therefore the conditions of growth may affect the yield and content of Eos[18]. Rebey et al. (2012) found that a moderate water deficit (MWD) increased the number of seeds produced by cumin plants but a severe water deficit (SWD) decreased yield. Essential oil yield increased by 1.4 fold under MWD, but decreased by 37.2% under SWD in comparison. Water deficits also changed the profile of constituents in EOs from predominantly γ-terpinene/phenyl-1,2 ethanediol in the control seeds to γ-terpinene/cuminaldehyde in stressed ones[19]. Badi, Yazdani, Ali, and Nazari (2004) studied the effects of plant spacing and time of harvest on the yield of EOs in thyme. It is clear that the different treatments did not show big change in the main constituents of the essential oil, which may be attributed to that the biosyntheses of these compounds did not affect by these treatments[20]. Plants were harvested either at the beginning of blooming, full blooming or fruit set. Planting space did not significantly affect EO content, but time of harvest did. The maximum yield of EO and of thymol content were obtained when plants were placed 15 cm apart and harvested at the beginning of blooming stage[21]

4. Mode of action of essential oils

The antimicrobial effects of EOs have been screened against a wide range of microorganisms over the years, but their mechanism(s) of action are still not completely understood. Several mechanisms have been proposed to explain the actions of the chemical compounds contained in the Eos[5]. Essential oils are composed of several components and their antimicrobial activity cannot be confirmed based only on the action of one compound[22]. Several researchers have proposed that the antimicrobial action of EOs may be attributed to their ability to penetrate through bacterial membranes to the interior of the cell and exhibit inhibitory activity on the functional properties of the cell, and to their lipophilic properties[22]. The phenolic nature of EOs also elicits an antimicrobial response against foodborne pathogen bacteria[22]. Phenolic compounds disrupt the cell membrane resulting in the inhibition of the functional properties of the cell, and eventually cause leakage of the internal contents of the cell[22,23]. Phenolic compounds such as flavonoids can protect cells against reduced glutathione via increasing antioxidant enzymes' capability (such as glutathione peroxidase)[24,25].

The mechanisms of action may relate to the ability of phenolic compounds to alter microbial cell permeability, damage cytoplasmic membranes, interfere with cellular energy (ATP) generation system, and disrupt the proton motive force[22]. The disrupted permeability of the cytoplasmic membrane can result in cell death[26].

5. Antimicrobial effects of EOs

Essential oils[52-54] have been documented to be effective antimicrobials against several foodborne pathogens including *Escherichia coli* O157:H7, *Salmonella* Typhimurium, *Staphylococcus aureus*, *Listeria monocytogenes, Campylobacter* and others[27,28]. Cherrat et al. (2014) screened EOs derived from *Laurus nobilis* and *Myrtus communis* for *in vitro* antimicrobial activity against several foodborne pathogens. The EOs inhibited the growth of all bacterial strains with the EO derived from *L. nobilis* showing the strongest activity and EO from *M. communis* showing moderate to weak activity. In general, both EOs were more active against Gram-positive than Gram-negative bacteria. The bacteria least resistant to both EOs were *S. aureus*, and the most resistant strains were *L. monocytogenes* EGD-e among the Gram-positive and *E. coli* O157:H7 among the Gram-negative strains[29].

Karsha and Lakshmi (2010) determined the minimal inhibitory concentrations (MICs) of extracts of black pepper against *Staphylococcus*, *Bacillus* and *Streptococcus* were 125, 250, and 500 ppm, respectively. *Pseudomonas* was found to be more susceptible to black pepper extracts followed by *Escherichia coli*, *Klebsiella*, and *Salmonella* (62.5, 125 and 250 ppm MIC, respectively)[30]. Sheng and Zhu (2014) studied the effects of EOs derived from *Cinnamomum cassia* for antibacterial activity against the "top six" non-O157 Shiga-toxin producing *E. coli* (STECs) O26, O45, O103, O111, O121, O145. The major component of the EO was cinnamaldehyde (59.96%). Minimum inhibitory concentration for all tested non-O157 STECs was 0.025% (v/v), but the minimum bactericidal concentration was strain dependent varying from 0.05% (v/v) to 0.1% (v/v). Including 0.025% (v/v) of the EO in growth medium completely inhibited the growth of all tested non-O157 STECs for at least 24 h[25]. Some EOs and their components have been shown to have the capacity to function as antimicrobials at low storage temperatures. Citrus EOs were investigated for their ability to reduce or eliminate *E. coli* O157:H7 or *Salmonella* inoculated onto beef at the chilling stage of processing, or during fabrication[31]. The EOs were applied after inoculation by spraying at concentrations of 3% and 6% to the surface of different pieces of meat. The Eos significantly reduced the concentration of *E. coli* in comparison to inoculated-no spray or water sprayed controls over a period of 90 days at refrigerated storage; total aerobic bacteria and psychrotrophic counts were also reduced on uninoculated briskets following treatment[32]. Pendleton, Crandall, Ricke, Goodridge, & O'Bryan (2012) likewise found that cold pressed terpeneless Valencia oil was effective at refrigeration temperatures to reduce growth of several strains of *E. coli* O157:H7 isolated from beef[33].

6. EOs in food systems

In different communities, medicinal plants have long been used to manage pain and treat diseases, and currently, the medicinal plants and plantbased products, alongside synthetic drugs, are being used[34]. Factors present in complex food matrices such as fat content, proteins, water activity, pH, and enzymes can potentially diminish the efficacy of Eos[35]. Bukvicki et al. (2014) evaluated the effects of *Satureja horvatii* in a ground pork product. The main components of the oil were p-cymene (33.1%), thymol (26.1%) and thymol methyl ether (15.1%). The EO inhibited growth of *L. monocytogenes* inoculated into the meat. The color and flavor of uninoculated meat treated with the EO improved during 4 days of refrigerated storage[36]. da Silveira et al. (2014) evaluated the antimicrobial activity of bay leaf EO in fresh Tuscan sausage stored at 7°C for 14 d. Sausages were treated at 0.05 g/100 g or 0.1 g/100 g and their shelf life was compared to a non-treated control. The EO was able to reduce the population of total coliforms by nearly 3 log CFU/g and to extend the product shelf life for two days[37].

Nano- or microencapsulation of EOs could offer possible solutions to solve challenges facing their applications in food. Pan et al. (2014) studied thymol encapsulated in sodium caseinate and found that the encapsulated thymol was more effective than un-encapsulated thymol in inhibiting foodborne pathogens in milk, due to the enhanced distribution and solubility of the encapsulated EO[38]. Chen, Zhang and Zhong (2015) co-encapsulated eugenol and thymol in zein/casein nanoparticles which were subsequently spray dried. The spray dried complexes rehydrated easily and produced a stable dispersion. The encapsulated EOs showed controlled release in 24 h, with the encapsulated eugenol showing a higher release rate than thymol. Bactericidal and bacteriostatic effects were observed in milk whey for *E. coli* O157:H7 and *L. monocytogenes* Scott A, respectively[39].

Peretto et al. (2014) prepared edible films of strawberry puree with carvacrol and methyl cinnamate and used them in clamshells to provide controlled release of vapors without direct contact with the fruit. Fresh strawberries were packed in the clamshells and kept at 10°C for 10 days with 90% relative humidity. They observed a significant delay and reduction in the severity of visible decay in fruit that was packed in the clamshells with the treated films and berries remained firmer and brighter in color as compared to untreated strawberries. Mushrooms are a fresh product that are subject to rapid deterioration due to their delicate nature as well as high respiration rate which contributes to enzymatic browning. Active packaging using EOs could be one solution to this problem[40].

Gao, Feng and Jiang (2014) fumigated button mushrooms with EOs including clove, cinnamaldehyde, and thyme and determined effects on browning and postharvest quality during 16 days of cold storage. Results indicated that all EOs could inhibit the senescence of mushrooms, although the most effective compound was cinnamaldehyde[41]. Echegoyen and Nerin (2015) determined the effect of active packaging with cinnamon oil on postharvest deterioration in mushrooms. They found that the active packaging prevented weight loss and browning when compared to non-active paraffin based packaging. They also found better results when the bottom and walls of the trays were covered as compared to the bottom alone[42].

7. Essential oils extraction methods

EOs are obtained from plant raw material by several extraction methods[43]. Such methods could be classified into two categories: conventional/classical methods and advanced/innovative methods. Investigation in new technologies (ultrasound, microwave) in the last decades has led to the emergence of new innovative and more efficient extraction processes (reduction of extraction time and energy consumption, increase of extraction yield, improvement of Eos quality).

7.1. Conventional and classical methods

These are conventional methods based on water distillation by heating to recover EOs from plant matrix.

7.1.1. Hydrodistillation

This method is the most simple and old that is used for the extraction of Eos[44]. Historically, Avicenna, (980–1037), was the first to develop extraction through the alembic. He has extracted the first pure essential oil that of the rose. The plant material is immersed directly in the water inside the alembic and the whole is brought to boiling. The extraction device includes a source of heating surmounted by a vessel (alembic) in which we could put plant material and water.

7.1.2. Cold pressing

Cold pressing is the traditional method to extract EOs from citrus fruit zest. During extraction, oil sacs break and release volatile oils which are localized in the external part of the mesocarpe (sacs oils or oil glands). This oil is removed mechanically by cold pressing yielding a watery emulsion. Oil is recovered subsequently by centrifugation[45]. In this case we obtain the vegetable essence of citrus zest which is used in food and pharmaceutical industries and as flavoring ingredients or additives (food industry, cosmetics and some home care products).

7.2. Innovative techniques of essential oils extraction

One of the disadvantages of conventional techniques is related with the thermolability of EOs components which undergo chemical alterations (hydrolyse, isomerization, oxidation) due to the high applied temperatures. The quality of extracted EOs is therefore extremely damaged particularly if the extraction time is long. It is important that extraction methods could maintain Eos chemical composition and natural proportion at its original state. New extraction techniques must also reduce extraction times, energy consumption, solvent use and CO_2 emissions.

7.2.1. Microwave assisted extraction (MAE)

Microwaves are electromagnetic based waves with frequency between 300 MHz and 30 GHz and a wavelength between 1 cm and 1m. The commonly used frequency is 2450 MHz which corresponds to a wavelength of 12.2 cm. The use of MAE evolved with the development of the green extraction concept and the need for new energy saving extraction methods. More attention has been paid to the application of microwave dielectric heating for Eos extraction. Starting from compressed air microwave distillation (CAMD) and vacuum microwave hydrodistillation (VMHD), innovation in the microwave assisted extraction (MAE) led to the development of a large number of variants such as microwave assisted hydrodistillation[46], solvent free microwave extraction (SFME)[47], microwave-accelerated steam distillation (MASD)[48], microwave steam distillation[49], microwave hydrodiffusion and gravity (MHG)[50] and portable microwave assisted extraction (PMAE). The MAE, largely developed by Chemat and co-workers, became rapidly one of the most potent EOs extraction methods and one of the upcoming and promising techniques. It offers high reproducibility in shorter times, simplified manipulation, reduced solvent consumption and lower energy input.

7.2.2. Solvent free microwave extraction (SFME)

This method was developed by Chemat and co-workers[47]. Based on the combination of microwave heating energy and dry distillation, it consists on the microwave dry-distillation at atmospheric pressure of a fresh plant without adding water or any organic solvent[51].

8. Conclusion

Essential oils are natural products which consist of complex blends of many volatile molecules. They have been used for several applications in pharmaceutical, cosmetic, agricultural, and food industries. Extraction could be carried out by various techniques. Innovative methods avoid shortcomings of conventional techniques like chemical alteration risk, long extraction time and high energy input. Despite their numerous applications, essential oils are very sensitive to environmental factors when used as such. Nowadays the combination of essential oils and active molecules is attracting special attention in order to obtain colloidal particles mainly for dermatology, local skin therapy and now cosmeto-textile as new application.

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