Role of Natural Essential Oils in Sustainable Agriculture and Food Preservation

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Author’s contribution

This whole work was carried out by the author MAB.

ABSTRACT

Research on humans, animals or plants about anti-inflammatory, anticancer, antiviral, repellent, antibacterial, antifungal or antioxidant activities of the essential oils corroborated the biological characteristics of aromatic plants and their use since ancient times for their preservative and medicinal properties. These mixtures of natural compounds are valuable ingredients in perfumery, food, agricultural and pharmaceutical industries. Currently, consumer demand natural products, effective, safe and environmentally friendly. Among them, essential oils may be natural alternatives of synthetic herbicides for organic farming systems, solving serious environmental problems due to their low persistence in the field as well as the incidence of resistance in both weeds and some pathogens. Correlations between the principal compounds of essential oils with herbicidal effect than explain their use in a sustainable agriculture or their antibacterial activity against food borne pathogens, food spoiling bacteria and bacterial virulence factors as biofilm formation for the use as natural food preservative are the main focus of this review.

Keywords: Essential oil; herbicidal activity; antimicrobial activity; food preservatives.

1. INTRODUCTION

Essential oils, complex oil mixture easily and economically obtained by steam distillation from different parts of aromatic plants or by cold-pression (Citrus fruits), are widely used in
perfumery, cosmetic, food, beverage, agricultural and pharmaceutical industries. Several studies have demonstrated that depending on its composition, certain essential oils are responsible for a large number of pharmacological activities such as expectorant (e.g. eucalyptus essential oil) rubefacient (e.g. turpentine and rosemary essential oils), carminative, eupeptic, antispasmodic (e.g. chamomile and mint essential oils), antiseptic (e.g. thyme, oregano essential oils), antibacterial (e.g. eucalyptus and thyme essential oils), anti-inflammatory (e.g. chamomile essential oil,) etc. It is well known that carminative, eupeptic and antispasmodic properties are related to essential oils with anethol; rubefacient property are attributed to essential oils rich in camphor or antiseptic activity are related with essential oils with high content in phenolic compounds such as thymol or carvacrol. Recent investigations corroborated that the anti-inflammatory activity of chamomile essential and their use in inflammatory disorders of the gastrointestinal tract [1] is due to both sesquiterpene compounds, α-bisabolol and chamazulene. In response to carrageenan, the oxygenated sesquiterpene α-bisabolol decreased leukocyte migration, protein extravasations and the amount of TNF-α in rat peritoneal cavity [2], whereas the sesquiterpene hydrocarbon chamazulene, was able to suppress the formation of leukotiene B4 in the neutrophilic granulocytes [3]. In the last years a wide range of promising biological activities, such as herbicide [4], fungicide [5,6], larvicide [7,8], insecticide [9], or leishmanicidal [10,11,12] with application in different sectors, have been demonstrated for certain essential oils. In addition a large number of researches are conducted about the antioxidant activity of the essential oils [13,14,15], because oxidation process is responsible of the biological substances damages and subsequently cause of many disorders, including atherosclerosis, arthritis, diabetes, cancer, Parkinson’s disease or Alzheimer disease [16,17,18,19,20,21,22]. From a chemotaxonomic point of view, the essential oil composition has been particularly helpful in assessing taxonomic relationships [23] of several species with high similarities in morphological characters especially in leaves, trichomes, and flowers. It has been discussed the convenience or not to use the volatile components of plants as taxonomic criteria, due to the high variability observed in different populations of the same species or even between species of the same population [24]. However if the essential oil composition, taken separately may be lower than other phytochemical groups such as flavonoids, diterpenes or alkaloids, this inferiority can be offset by using the concentration of different main compounds in the plant or better yet, the presence or absence of several components because it reflect the outcome of a series of metabolic processes that although affected by environmental variables (soil, climate) or age of the aromatic plant must be the results of its biochemistry and genetic structure [25]. In this sense, the essential oil composition has been of great help in solving chemotaxonomic problems in several genera and species of different families like Labiatae, i.e. Salvia [26], Teucrium [27,28], Satureja [29] or Thymus [30]. The aim of this overview is to summarize some aspects of the essential oil composition, to emphasize about the herbicidal activity in order to use the essential oils in sustainable agriculture and to focus the antimicrobial activity exhibited by some essential oil in controlling bacterial virulence factors such as biofilm formation or in the use as natural antimicrobial agents in edible packaging materials.

2. ESSENTIAL OIL COMPOSITION

The wide range of biological activities showed by the essential oil is related to the qualitative and quantitative composition of these natural volatile mixtures. We can found terpenoids (monoterpenes, sesquiterpenes and diterpenes in the form of hydrocarbons, alcohols, aldehydes, ketones, ethers, esters, peroxides and phenols), aromatic compounds (C6-C3 and C6-C1 compounds) less frequent but characteristic of certain essential oils and low
molecular weight aliphatic compounds (hydrocarbons, alcohols, acids, aldehydes, esters and lactones) with different physical, chemical and pharmacological properties, responsible of the activity of whole essential oil. It is very important to know not only botanical classification but also their origin, harvest time, extraction process and analytical techniques in order to ensure quality in both chemotaxonomic and pharmacological purposes. To obtain essential oils from aromatic plants only the conventional method, steam distillation (hydrodistillation, saturated steam, dry steam) must be employed according to the recommendations of the European Pharmacopoeia [31].

Innovative techniques, ultrasound assisted extraction and microwave assisted extraction techniques such as in situ microwave-generated hydrodistillation, microwave steam distillation, microwave hydrodiffusion and gravity, and microwave steam diffusion than can reduce the time of extraction may be used [32], but could be modified their natural composition, mainly the quantitative composition. It is well known that the essential oil of several species are different according to the geographical origin, and in this sense for *Artemisia arborescens*, chamazulene (American oil) or β-thujone (Morocco oil) type has been reported [33]. The quantitative prevalence of β-thujone (33.4±4.55; 42.6±6.13) and chamazulene (28.1±3.64; 24.4±6.56) at the vegetative and flowering stage respectively was the prominent chemical characteristic of the *A. arborescens* essential oil from Sicilian [34]. In other cases geographical origin affects both qualitative and quantitative composition of the essential oils. In this way *Lantana camara* L., an aromatic shrub native to tropical America, considered one of the worst weed [35], grows in Europe and other regions as ornamental plant. Although their essential oil contains the sesquiterpene hydrocarbons as the main phytochemical group, there are many differences with other fractions and also with the main compounds. In Spain monoterpenes fraction, both oxygenated and hydrocarbons were no detected being the main compounds the sesquiterpene hydrocarbons α-curcumene (23.1%) followed by β-caryophyllene (17.5%) and γ-curcumene (14.6%) [36] whereas in Algeria and India *L. camara* elaborate an essential oil with monoterpene compounds and with great differences in the sesquiterpene oxygenated fraction. β-caryophyllene was the main compound in both countries (35.7% and 23.3% respectively), followed in Algeria by caryophyllene oxide (10.0%) [37] whereas this oxygenated sesquiterpene only reach 0.3 % in India [38] being the main compound of this fraction davanone (7.3%), compound which was only present in 0.3% in the essential oil of *L. camara* from Algeria. Together with the geographic origin of the specie it is highly relevant to know the variety. Certain bioactive compounds such as zerumbone (Fig. 1) with interesting antitumor [39,40] and antiinflammatory [41,42] properties only occur in the essential oil of several *Zingiber* species and varieties. Zerumbone was no present in the essential oils obtained by hydrodistillation in a Cleaveger type apparatus from the rhizome of *Z. officinale* (L.) Roscoe in samples collected in India (α-zingiberene 8.2%, geranial 15.0% and neral 10.6%) [43] and Brasil (α-zingiberene 23.8%, geranial 14.2% and (E,E)-α-farnesene 10.0%) [5], being found in large amount in the essential oils also obtained by hydrodistillation from the fresh rhizomes of *Zingiber zerumbet* Smith (zerumbone 88.5%, α-humulene 2.3%) [43] and *Zingiber zerumbet* var. *darcy* (zerumbone 69.9%, α-humulene 12.9%) [44] collected in India (Fig. 1). Both essential oils became the best natural biological source for the isolation of the oxygenated sesquiterpene zerumbone used in pharmacological assays.
Finally, regarding the chemical composition of an essential oil, GC-FID (Gas Chromatography coupled with Flame Ionization Detection) and GC-MS (Gas Chromatography - Mass spectrometry) are the best standard techniques for their analysis being employed for more than 90% of the researchers. Although other associated spectroscopic techniques, including IR (Infrared), FT-MIR (Fourier Transform-Middle Infrared spectrometry) Nuclear Magnetic Resonance (\(^1\)H and \(^{13}\)C-NMR), HPLC-UV (High Performance Liquid Chromatography coupled with Ultra-Violet detection) HPLC-Mass (High Performance Liquid Chromatography - Mass Spectrometry) could be advantageous in the
identification and quantification of certain compounds in several essential oils [45,46] are more expensive analysis. In summary, standardized processes with these volatile constituents are essential to assure a constant biological activity.

3. BIOLOGICAL ACTIVITIES OF THE ESSENTIAL OILS

Essential oils in addition to their aromatic properties own biological activities closely linked to their chemical composition and related with environment and human health. Their use to treat respiratory tract, digestive system or skin infections diseases have been confirmed. Patent US 7048953 [47] describes methods of inhaling the vapors of essential oils, including eucalyptus oil (Eucalyptus globulus) and tea tree oil (Melaleuca alternifolia) to prevent, treat, and cure infections of Severe Acute Respiratory Syndrome (SARS) and more recent patents are about essential oils or their components in new promising biological activities such as herbicidal or inhibition of both microorganism growth and biofilm formation [48,49].

3.1 Herbicidal Activity

The development of agrochemical products between 1940-1990s, based on the employment of chemical fertilizers and pesticides increased agricultural productivity. However the overuse of agrochemicals such as synthetic herbicides involved the emergence of resistant strains of weed and also its accumulation in soils and ground water with adverse effects in living organism and human health. The firsts resistances were observed in the 50s, in flies and mosquitoes, but the real health problem was demonstrated when it was found that not only was produced in insect of agricultural plagues, but also in other transmitters of human diseases, such as the emergence of resistance in the vectors of malaria in 1960 [50]. This has driven the search of alternative methods for weed control, based on natural products possessing safety with both environmental and human health. Between natural substances described as inhibitors of seed germination and seedling growth we can found cinnamic acid derivatives, coumarins, flavonoids, alkaloids, cyanoglycosides and amino acids together terpenoids, including volatile terpenes that are the main compounds of the essential oils [51,52,53,54,55,56,57,58,59]. In plants, it is well known that essential oil plays an important role in defense mechanism, especially against herbivores, damaging insects or fungal pathogens [60]. Volatile terpenoids also act in plant-plant interactions, being attractant agents in insect pollination [61]. Several essential oils or its components have been employed in different herbicide formulations [48,62]. The advantage of using volatile herbicides is due to their low persistence in the field when compared with nonvolatile herbicides [63], being their use promising in organic agriculture for weed control, but also the main problem is its volatility needing to emulsify the essential oil with surfactants to improve efficiency or using alternative formulations, such as microencapsulation that are recently develop to increase the duration its effect, reducing volatilization and slowing its degradation in the environments [64,65,66]. Several essential oil show great species-specific toxicity against seed germination, without effects o even with stimulatory effect in others [36,67]. Preliminary studies showed than oxygenated monoterpenes are more phytotoxic compounds than monoterpenic hydrocarbons [68,69,70,71]. In this way carvacrol, carvone, thymol, trans-anethole and linalool were the most phytotoxic components completely inhibiting rigid ryegrass germination and root length at 160 nL/cm², whereas the monoterpenic hydrocarbons myrcene, β-pinene, α-pinene, limonene, ocimene and p-cymene were slightly phytotoxic [72]. Also herbicidal activity was showed when a mixture of oxygenated monoterpenes (carveol, carvone, menthone, and carvyl acetate) together the oxygenated sesquiterpenic cedrol was tested in green house on paddy weeds [73,74], being the high
content of the oxygenated monoterpenes nepetalactones (92.23%), in *Nepeta meyeri* Benth essential oil, the responsible of the inhibition of seed germination and seedling growth of *Amaranthus retroflexus* L., *Portulaca oleracea* L., *Bromus danthoniae* Trin., *Agropyron cristatum* L., *Lactuca serriola* L., *Bromus tectorum* L., *Bromus intermedius* Cuss., *Chenopodium album* L., *Cynodon dactylon* L. and *Convolvulus arvensis* L. [75].

Herbicidal activity was also observed with oxygenated monoterpene derivatives, so hydroxy and ester derivatives of 1,8-cineole (main compound in *Eucalyptus* sp. essential oils) and 1,4-cineole showed a dose-dependent herbicidal activity against annual ryegrass (*Lolium rigidum*) and radish (*Raphanus sativus* var. *long Scarlet*) [76]. Others oxygenated monoterpenes such as camphor, 1,8-cineole, borneol, thymol and carvacrol are responsible of inhibitory effect in both crops and weeds [51,77,78,79]. In this sense the high content of artemisia ketone (56.46%) in the essential oil of *Eriocephalus africanus* L. [36] can be explain their phytotoxic activity against Mediterranean summer crops, as occur in other *Artemisia* species with allelopathic properties [80]. However not only monoterpene compounds are responsible for germination inhibition [70,71], being the strong inhibitory effect of *Eucalyptus camaldulensis* Dehn. essential oil [36] attributed to the large content of oxygenated sesqui-terpenes (48.27%) mainly by the presence of spathulenol (41.46%) suggesting according to other authors [77] than 1,8-cineole is not the principal responsible for the phytotoxic effect of *Eucalyptus* sp. essential oil.

In other cases the essential oil is more active than their main oxygenated monoterpenic compound. Clove essential oil (*Syzygium aromaticum* (L.) Merr. and Perr. caused greater inhibition of seedling growth against broccoli (*Brassica oleracea* var. *italica*), common lambsquarters (*Chenopodium album* L.) and redroot pigweed (*Amaranthus retroflexus* L.) than their main compound eugenol [81]. Or even essential oil with high content on monoterpenic hydrocarbons can be more effective than essential oil with large amount of oxygenated monoterpenes against certain weed. A comparative study between leaves essential oils of *Citrus limon* (L.) Burm.f., *Citrus sinensis* (L.) Osberk, *Myrthus comunis* L. and *Laurus nobilis* L., all rich in monoterpenic fractions against the same weed (*Araujia sericifera* Brot.) showed that the more phytotoxic effect depended of the monoterpenic hydrocarbons. The most effective essential oils against seed germinations was lemon essential oil, completely inhibiting seed germinations at 0,250,0,5 and 1 µL/mL (unpublished data), followed of orange essential oil, myrtle essential oil and bay leaf essential oil (Fig. 2). *C. sinensis* essential oil with 69.72% of monoterpenic hydrocarbons was more active than *Myrthus comunis* L. and *Laurus nobilis* essential oils with 74.76% and 60.82% respectively of the oxygenated monoterpenes. The main compounds of *C. sinensis* was sabinene 30.09±2.88, trans-ocimene 9.05±0.66 and 3-carene 8.50±2.06, however the less active essential oil *L. nobilis*, contains large amounts of oxygenated monoterpenes 1,8-cineole 33.13±7.37, α-terpinyl acetate13.02±2.25 and the phenylpropanoid methyl eugenol 12,88±1,79 (unpublished data). It is interesting to note that the most effective essential oils against *A. sericifera*, a weed in *Citrus* is accurately the essential oils produced in the leaves of cultivar *Citrus* trees from Valencia (Spain).

On the other hand, when we compare in vitro the phytotoxic activity between the essential oils and aqueous extracts of the same biological raw material, in general in vitro essential oils are more active in both seed germination and seedling growth against weeds, but again it is related to the composition and weed applied [36,82]. The essential oil of *E. camaldulensis* Dehn. was the most effective, completely inhibiting both *Amaranthus hybridus* L. and *Portulaca oleracea* L. seed germination [36], and also *E. camaldulensis* aqueous extract was the most effective reducing *A. hybridus* germination. *Eriocephalus*
africanus L. extract exhibited significant activity up to 30% concentration, while Lantana camara L. extract was least active. Against P. oleracea, E. africanus extract obtained the best results followed by E. camaldulensis extract, while L. camara extract showed no inhibitory effect [82]. In greenhouse assays (in trays with soil), the essential oils were less effective whereas all aqueous extract showed herbicidal activity against the same weed. E. africanus extract was the most effective (52.45% inhibition), followed by E. camaldulensis (38.43%) controlling seed germination during 6 week, whereas L. camara was less active (21.32%). In field conditions, E. africanum and E. camaldulensis extracts corroborated the results obtained under greenhouse conditions (68.9 and 39.6% maximum inhibition respectively); however L. camara was no active showing even stimulatory effect [83]. Although the essential oil of Ocimum basilicum L. against tomato, lettuce and melissa corroborated that the essential oil is more active than aqueous extract [84] in other species such as Tagetes minuta, the phytotoxic effect of aqueous extract is higher than their essential oil [85].

 Accordingly, the herbicidal potential of the essential oils depends on the composition, doses employed as well as on the weed against they are applied, being possible to develop specific herbicides for a particular weed.

![Fig. 2. Control (A. sericifera) and treatment with essential oil of Laurus nobilis after 5, 10, 14 days of incubations (unpublished data)](image)

3.2 Antimicrobial Activity

Essential oils possess antimicrobial activity [86] and have been used for longtime [87,88,89] in folk medicine to treat infections, even replacing antibiotics in mild infectious diseases.

The existence of resistance development for commonly used antibiotics increase the search of natural additives with antimicrobial activity. The selective toxicity towards several pathogens and the synergism of individual components with different mechanism of action than hardly can develop resistance is the main remarkable properties to the essential oils. In food industry this antibacterial activity has been focused in both, directed against many food pathogens and food spoiling bacteria, including the biofilm formation inhibition making these
substances attractive as food preservatives and in the use of natural antimicrobial agents in edible packaging materials.

3.2.1 Food antimicrobial agents. Biofilm formation inhibitors

Antimicrobial activity of the essential oils is highly related with their qualitative and quantitative composition. L’Aromatogramme of thyme essential oils [90] showed that the oxygenated compounds play an important role in the antimicrobial activity against Escherichia coli ATCC 25922, Klebsiella pneumonia ATCC 18883, Pseudomonas aeruginosa ATCC 27853, Staphylococcus aureus ATCC 25923, Candida albicans ATCC 26555 and Mycobacterium phlei CECT 3009. Although S. aureus, C. albicans and M. phlei were inhibited by the same strip of Thymus leptophyllus and T. webbianus essential oils, the essential oil of T. webbianus showed a specific band against C. albicans attributed to the sesquiterpene hydrocarbons germacrene B (18.8%), calamenene, γ and δ-cadinene found in this oil.

Phenolic compounds commonly found in essential oils (thymol, carvacrol and eugenol) have antimicrobial activity against foodborne pathogens [91,92]. In agar well diffusion method thymol, carvacrol as well as thyme essential oil showed inhibitory effect on Shigella sonnei and S. flexneri, whereas eugenol by disc-diffusion method, at 0.0125% MIC (minimal inhibitory concentration,) and 0.025% MBC (minimum bactericidal concentration) produced complete inhibition of Salmonella typhi. The antibacterial activity of eugenol against Salmonella typhi according to the authors is due to the interaction on bacterial cell membrane [92]. The damage in membrane integrity was also observed in the total inhibition of Pseudomonas aeruginosa and Staphylococcus aureus with thymol and carvacrol [93]. In addition to phenolic compounds, oxygenated monoterpenes (linalool, 1,8-cineole, α-terpineol) or even monoterpenic hydrocarbons (α-pinene) compounds usually presents in many essential oil are responsible of the antimicrobial activity against potential food spoilage microorganisms [94]. The most effective (bacteriostatic/bactericidal effects) antimicrobial natural compound against Aeromonas hydrophila, Escherichia coli, Brochothrix thermosphacta, and Pseudomonas fragi, was thymol (40 pp/100ppm) followed by carvacrol (50 ppm/100 ppm), linalool (180 ppm/720 ppm), α-pinene (400 ppm/no bactericidal effect), 1,8-cineol (1,400 ppm/2,800 ppm), and α-terpineol (600 ppm/no bactericidal effect). Thymol and carvacrol were the most effective combination against all tested bacteria. The addition of linalool to each showed a synergistic antibacterial effect depending on their concentration. Phenolic compounds combined with α-terpineol led to a synergistic antimicrobial effect against A. hydrophila, E. coli, and P. fragi however produced antagonistic effects against B. thermosphacta [94]. Regarding essential oils, Laurus nobilis essential oil (1,8-cineole 39.81%) showed bacteriostatic and bactericidal effects against Salmonella enteric subsp. enterica serovar Senftenberg (CECT 4563), Escherichia coli O157:H7,22, Escherichia coli (CECT 471), Yersinia enterocolitica (CECT 4315), Staphylococcus aureus (CECT 976), Enterococcus faecium (CECT 4932), Listeria monocytogenes (CECT 4031), Listeria monocytogenes EGD-e and Bacillus subtilis (CECT 4071) whereas Myrtus communis essential oil with large amount of myrtenyl acetate (49.27%), 1,8-cineole (26.93%) and α-pinene (16.52%) was not found to be bactericidal activity [95].

Although, many essential oils compounds possess antibacterial properties, even higher than oleoresin their strong flavoring properties limit their usage as food antimicrobial agents [96]. Search of essential oils with potent bactericidal effect and do not affect the flavor and taste
of food products is the first limitation of use. Food quality and safety is essential for both consumers and food industry.

Antimicrobial activity of essential oils can be reduced by storage conditions and also by bacteria (e.g. *Pseudomonas* sp., *Staphylococcus aureus*) with the ability to produce biofilms with an additional protection against a wide range of antimicrobials [97,98]. Biofilms have been implicated in serious human infections and are responsible of 90% of chronic infections. Bacterial biofilms are complex communities of bacteria embedded in a self-produced matrix and attached to inert or living surfaces. These microorganism communities are more resistant to both antibiotics and immune system. Microbial biofilms are an important problem in food and pharmaceutical industries, being responsible of principal foodborne diseases. In the United States yearly, 31 pathogens caused 37.2 million (90% CrI 28.4-47.6 million) illnesses, of which 36.4 million (90% CrI 27.7-46.7 million) were domestically acquired; of these, 9.4 million (90% CrI 6.6–12.7 million) were foodborne. The 59% of foodborne illnesses were caused by viruses, 39% by bacteria and 2% by parasites [99].

Natural compounds controlling bacterial virulence factors such as biofilm formation (that show also high resistance against cleaning and disinfecting reagents) are interesting to prevent the development of resistant strains [100].

Spices in food products are mainly used to enhance flavour and taste, but also have antimicrobial properties [101] and in this sense the essential oils of spices, *Citrus* [102] or other genera could be applied as natural food preservatives [103].

Several studies are aimed in order to evaluate if essential oils with demonstrated antimicrobial activity are able to inhibit biofilm formation and therefore have effect to prevent foodborne diseases. Oregano essential oil, carvacrol and thymol are able to reduce biofilm formation in several strains of *Staphylococcus aureus* and *S. epidermidis* [104]. Similar results were found with thyme essential oil, oregano essential oil and carvacrol against *Salmonella typhimurium* [105]. More recently Szczepanski and Lipski [106] reported that thyme, oregano and cinnamon essential oils showed inhibiting effect on biofilm formation below their minimal inhibitory concentration. The three essential oils showed antimicrobial effect on planktonic cell of strains of the genera *Acinetobacter*, *Sphingomonas* and *Stenotrophomonas*. The minimal inhibitory concentration (MIC) of the essential oils ranged from 0.016% for thyme and oregano essential oils on *Sphingomonas* spec. up to 0.063% for cinnamon essential oil on *Acinetobacter* spec. [106]. The isolate of *Stenotrophomonas* genus showed highest MIC against all tested essential oils, being not effective in biofilm formation. Biofilm formation of the *Sphingomonas* and the *Acinetobacter* strain was inhibited below 50% of the minimal inhibitory concentration of the essential oil, whereas the biofilm formation of the *Stenotrophomonas* strain was not inhibited below MIC. On the other hand, mandarin essential oil with high content of monoterpenic hydrocarbons limonene (89.82%), γ-terpinene (2.76%) and myrcene (2.51%) was not active against *Pseudomonas aeruginosa* ATCC 27853 growth, however at the same doses (1, 0.1 mg/ml) the inhibition of bacterial biofilm formation was similar and higher respectively to azithromycin at 5μg/ml used as positive control [98]. So, essential oils with high content in both oxygenated and hydrocarbons monoterpenene can inhibit biofilm formation from specific foodborne bacteria.
3.2.2 Food antimicrobial agents, Edible package antimicrobial

Reduce or eliminate food-related microorganisms without negative effects on food quality throughout the shelf life of food products is a challenger to food industry. The use of antimicrobial biodegradable films (a partial alternative to plastic packaging) are increasing in order to delay microbial spoilage of food and reduce or inhibit foodborne pathogens.

In concerning to the incorporations of essential oils into edible films it is important to known the effect that they can produce [107,108]. In some cases, such as occur with the addition of oregano essential oil to alginate films, the obtained films were less rigid, more flexible, and less transparent, compared with the control film [109].

Among the many materials, proteins, lipids and polysaccharides that can form edible films, alginate a water-soluble polysaccharide and chitosan [109,110,111] has been extensively investigated.

The essential oils of clove (Syzgium aromaticum L.), cumin (Cuminum cyminum L.), caraway (Bunium persicum Bioss.), marjoram (Origanum majorana L.), cinnamon (Cinnamomum zeylanicum Blumen), coriander (Coriandrum sativum L.), fennel (Foeniculum vulgare Miller), cypress (Cupressus sempervirens L.), lavender (Lavandula angustifolia Miller), thyme (Thymus vulgaris L.), herb-of-the-cross (Verbena officinalis L.), pine (Pinus sylvestris L.) and rosemary (Rosmarinus officinalis L.) have been tested against common foodborne pathogens in order to determine their antimicrobial activity (Staphylococcus aureus, Listeria monocytogenes, Escherichia coli, Pseudomonas fluorescens, Shewanella putrefaciens, Photobacterium phosphoreum, Listeria innocua, Lactobacillus acidophilus, Pseudomonas putida, Streptococcus agalactiae or Lactococcus lactis) before and after their incorporation into several films [112,113,114]. The antimicrobial activity varies according both the essential oil used and microorganism tested. Between the essential oils tested against S. aureus, E. coli and L. monocytogenes, marjoram, essential oil showed the stronger antibacterial activity followed to clove, cinnamon, coriander, caraway and cumin [113]. Clove, thyme and rosemary were the most active against Lactobacillus acidophilus, Listeria monocytogenes, Escherichia coli, Pseudomonas fluorescens, Photobacterium phosphoreum and Shewanella putrefaciens [112]. In general, gram-negative microorganisms are more resistant due to the external lipopolysaccharide wall which may prevent active components from reaching the cytoplasmic membrane [103].

When essential of marjoram, clove and cinnamon were incorporated to alginate-clay nanocomposite film, regardless of the composition of essential oil (terpinen-4-ol, eugenol, and cinnamaldehyde respectively as the main compound), the antimicrobial activity was maintained, but essential oil-enriched film showed less antibacterial activity in comparison with pure essential oil [113]. Similar results were obtained when oregano essential oil incorporated into alginate films was tested against Staphylococcus aureus, Listeria monocytogenes and Gram-negative bacteria as Escherichia coli and Salmonella enteritidis [109]. In general the activity of food packaging films depends on the nature and amounts of essential oil as well as the microorganisms tested and the effectiveness of the films tends to decrease during the storage period [113].

It is possible also develop antimicrobial films by the combinations of both an essential oil with mixture of films such as gelatin-chitosan biodegradable films [112] or two or three essential oils in the film matrix [115]. No differences between matrices (bovine-hide gelatin and chitosan edible films) in the antimicrobial activity were observed when clove essential oil
was incorporated. However some differences occur in water solubility between gelatin-chitosan-clove film and gelatin-clove film. The lower solubility of gelatin-chitosan-clove may be advantageous because essential oil could be released more slowly and maintain their effect for longer [112].

Chitosan enriched by lemon, thyme and cinnamon essential oil was investigated against \textit{E. coli} and \textit{S. aureus}. Chitosan-thyme essential oil exhibited the best antibacterial effect followed by the cinnamon and lemon essential oils. The combined use of two essential oils not caused synergistic effects being their antibacterial properties similar to a single essential oil, however the combination of two essential oils in the chitosan film had better water barrier properties and lower particle size [115]. This results shows that single essential oil or mixtures of them can be employed to enhance the antimicrobial activity against a particular microorganism.

4. CONCLUSION

The herbicidal and antimicrobial activities of essential oils is correlated with their chemical composition and depend of the doses employed as well as the weed or microorganisms against they are applied, being possible to develop specific herbicides or preservative substances for a particular weed or pathogen.

The use of essential oils providing additional antimicrobial (and/or antioxidant) property to edible films and coating, taking into account other aspects such as color or opacity of the films that must be accepted by the consumers, can extend shelf-life of food and become in an attractive option against foodborne diseases.

COMPETING INTERESTS

Author has declared that no competing interests exist.

REFERENCES

1. Srivastava JK, Gupta S. Health benefits of chamomile in Recent Progress in Medicinal Plants ed. by Awaad AS, Govil, JN and Singh VK. Studium Press, Houston; 2010.
2. Moura Rocha NF, Vasconcelos Rios ER, Rodrigues Carvalho AM, Santos Cerqueira G, De Araujo Lopes A, Moreira Leal LKA, Leite Dias M, Pergentino De Sousa D, Florenço De Sousa FC. Anti-nociceptive and anti-inflammatory activities of (–)-α-bisabolol in rodents. Arch Pharmacol. 2011;384:525-33.
3. Safayhi H, Sabieraj J, Sailer ER, Ammon HPT. Chamazulene: An antioxidant-type inhibitor of leukotriene B4 formation. Planta Med. 1994;60:410-13.
4. Verdeguer M, García-Rellán D, Boira H, Pérez E, Gandolfo S, Blázquez MA. Herbicidal activity of \textit{Peumus boldus} and \textit{Drimys winterii} essential oils from Chile. Molecules. 2011;16:403-11.
5. Garcia Yamamoto-Ribeiro MM, Grespan R, Yumie Kohiyama C, Dias Ferreira F, Galerani Mossini SA, Leite Silva E, Alves de Abreu Filho B, Graton Mikcha JM, Machinski JrM. Effect of \textit{Zingiber officinale} essential oil on \textit{Fusarium verticillioides} and fumonisin production. Food Chem. 2013;141:3147-52.
6. Tao N, Jia L, Zhou H. Anti-fungal activity of \textit{Citrus reticulata} Blanco essential oil against \textit{Penicillium italicum} and \textit{Penicillium digitatum}. Food Chem. 2014;153:265-71.
7. Romero MC, Valero A, Martín-Sánchez J, Navarro-Moll MC. Activity of Matricaria chamomilla essential oil against anisakiasis. Phytomedicine. 2012;19:520-23.
8. Cardoso Lima T, Mariano da Silva TK, Lima Silva F, Barbosa-Filho JM, Ortiz Mayo Marques M, La Corte Santos R, Cabral de Holanda Cavalcanti S, Pergentino de Sousa D. Larvicidal activity of Mentha x villosa Hudson essential oil, rotundifolone and derivatives. Chemosphere. 2014;104:37-43.
9. Ali A, Murphy CC, Demirci B, Wedge DE, Sampson BJ, Khan IA, Can Baser KH, Tabanca N. Insecticidal and biting deterrent activity of rose-scented geranium (Pelargonium spp.) essential oils and individual compounds against Stephanitis pyrioides and Aedes aegypti. Pest Manag Sci. 2013;69:1385-92.
10. Ríos YK, Otero AC, Muñoz DL, Echeverry M, Robledo SM, Yepes MA. Actividad citotóxica y leishmanicida in vitro del aceite esencial de manzanilla (Matricaria chamomilla). Rev Colomb Cienc Quím Farm. 2008;37:200-11.
11. Oliveira de Melo J, Bitencourt TA, Fachin AL, Oliveira Cruz EM, Ramos de Jesus HC, Barreto Alves P, Arrigoni-Blank MF, De Castro Franca S, Oliveira Beleboni R, Miranda Fernandes RP, Fitzgerald Blank A, Scher R. Antidermatophytic and antileishmanial activities of essential oils from Lippia gracilis Schauer genotypes. Acta Trop. 2013;128:110-15.
12. Monzote L, García M, Scull R, Cuellar A, Setzer WN. Antileishmanial activity of the essential oil from Bixa orellana. Phytotherapy Res. 2014;28:753-58.
13. Amiri H. Chemical composition and antioxidant activity of essential oil and methanolic extracts of Ferula microcolea (Boiss.) Boiss (Apiaceae). Int J Food Prop. 2014;17:722-30.
14. Jallali I, Zaouali Y, Missaoui I, Smeoui A, Abdelly C, Ksouri R. Variability of antioxidant and antibacterial effects of essential oils and acetic extracts of two edible halophytes: Crithmum maritimum L. and Inula crithmoides L. Food Chem. 2014;145:1031-38.
15. Amorati R, Foti MC, Valgimigli L. Antioxidant activity of essential oils. J Agr Food Chem. 2013;61:10835-47.
16. Yip YB, Tam AC. An experimental study on the effectiveness of massage with aromatic ginger and orange essential oil for moderate to severe knee pain among the elderly in Hong Kong. Complement Ther Med. 2008;16:131-38.
17. Adorjan B, Buchbauer G. Biological properties of essential oils: An updated review. Flavour Fragr J. 2010;25:407-26.
18. Komeh-Nkrumah SA, Nanjundaiah SM, Rajaiah R, Yu H, Moudgil KD. Topical dermal application of essential oils attenuates the severity of adjuvant arthritis in Lewis rats. Phytother Res. 2012;26:54-9.
19. Pagonopoulou O, Koutroumanidou E, Charalabopoulos K. Essential oils and neurodegenerative diseases: Current data and future perspectives. Curr Top Nutr Res. 2012;10:123-31.
20. Bhalla Y, Gupta VK, Jaitak V. Anticancer activity of essential oils: A review. J Sci Food Agric. 2013;93:3643-53.
21. Joo HE, Lee HJ, Sohn EJ, Lee MH, Ko HS, Jeong SJ, Lee HJ, Kim SH. Anti-diabetic potential of the essential oil of Pinus koraiensis leaves towards streptozotocin-treated mice and HIT-T15 pancreatic β-cells. BioSci Biotechnol Biochem. 2013;77:1997-2001.
22. Tang ELH, Rajarajeswaran J, Fung SY, Kanthimathi MS. Antioxidant activity of Coriandrum sativum and protection against DNA damage and cancer cell migration. BMC Compl Alt Med. 2013;13:347. Available: http://www.biomedcentral.com/1472-6882/13/347.
23. Sandasi M, Kamatou GPP, Combrinck S, Viljoen AM. A chemotaxonomic assessment of four indigenous South African Lippia species using GC-MS and vibrational spectroscopy of the essential oils. Biochem Syst Ecol. 2013;51:142-52.
24. Morales R. Taxonomía de los géneros Thymus (excluida la sección Serpyllum) y Thymbra en la Península Ibérica. Ruizia, Tomo 3. Consejo Superior de Investigaciones Científicas. Madrid; 1986.
25. Luro F, Venturini N, Costantino G, Paolini J, Ollitrault P, Costa J. Genetic and chemical diversity of citron (Citrus medica L.) based on nuclear and cytoplasmic markers and leaf essential oil composition. Phytochemistry. 2012;77:186-96.
26. Salimpour F, Mazooji A, Darzikolaei SA. Chemotaxonomy of six Salvia species using essential oil composition markers. J Med Plants Res. 2011;5:1795-1805.
27. Pérez I, Blázquez MA, Boira H. Chemotaxonomic value of the essential oil compound in species of Teucrium pumilum aggregate. Phytochemistry. 2000;55:397-401.
28. Blázquez MA, Pérez I, Boira H. Essential oil analysis of Teucrium libanitis and Teucrium turredanum by GC and GC/MS. Flavour Frag J. 2003;18:497-501.
29. García-Rellán D. Ecología química y actividad biológica de las especies perennes de Satureja L. en la Península Ibérica. PhD Thesis. Universidad Politécnica de Valencia; 2013.
30. Blázquez MA, Bono A, Zafrá-Polo MC. Essential oil from Thymus borgiae, a new Iberian species of the Hyphodromi section. J Chromatogr. 1990;518:230-33.
31. Council of Europe, Methods of Pharmacognosy. European Pharmacopoeia. 1997;3:121-22.
32. Pérono-Issartier S, Génies C, Cravotto G, Chemat F. A comparison of essential oils obtained from lavandin via different extraction processes: Ultrasound, microwave, turbohydrodistillation, steam and hydrodistillation. J Chromatogr A. 2013;1305:41-7.
33. Codignola A. L’huile essentielle d’Artemisia arborescens L. spontanée en Italie et cultivée au Maroc. Allioni. 1984;26:89-95.
34. Militello M, Currubba A, Blázquez MA. Artemisia arborescens L.: Essential oil composition and effects of plant growth stage in some genotypes from Sicily. J Essent Oil Res. 2012;24:229-35.
35. Pereira JM, Barreto RW, Ellison CA, Maffia LA. Corynespora cassicola f. sp. lantanae: A potential biocontrol agent from Brazil for Lantana camara. Biol Control. 2003;26:21-31.
36. Verdeguer M, Blázquez MA, Boira H. Phytotoxic effects of Lantana camara, Eucalyptus camaldulensis and Erioccephalus africanus essential oils in weeds of Mediterranean summer crops. Biochem System Ecol. 2009a;37:362-69.
37. Zoubiri S, Baaliouamer A. GC and GC/MS analyses of the Algerian Lantana camara leaf essential oil: Effect against Sitophilus granarius adults. J Saudi Chem Soc. 2012;16:291-97.
38. Rana VS, Prasad D, Blázquez MA. Chemical composition of the leaf oil of Lantana camara. J Essent Oil Res. 2005;17:198-200.
39. Kirana C, McIntosh GH, Record IR, Jones GP. Antitumor activity of extract of Zingiber aromaticum and its bioactive sesquiterpenoid zerumbone. Nut Cancer. 2003;45:218-25.
40. Murakami A, Tanaka T, Lee JY, Surh YJ, Kim HW, Kawabata K, Nakamura Y, Jiwajinda S, Ohigashi H. Zerumbone. A sesquiterpene in subtropical ginger, suppresses skin tumor initiation and promotion stages in ICR mice. Int J Cancer. 2004;110:481-90.
41. Murakami A, Takahashi D, Kinoshita T, Koshimizu K, Kim HW, Yoshihiro A, Nakamura Y, Jiwajinda S, Terao J, Ohigashi H. Zerumbone. A Southeast Asian ginger sesquiterpene, markedly suppresses free radical generation, proinflammatory protein production and cancer cell proliferation accompanied by apoptosis: The alpha, beta-unsaturated carboxyl group is a prerequisite. Carcinogenesis. 2002;23:795-802.

42. Murakami A, Takahashi D, Koshimizu K, Ohigashi H. Synergistic suppression of superoxide and nitric oxide generation from inflammatory cells by combined food factors. Mut Res. 2003;523-524:151-61.

43. Rana VS, Verdeguer M, Blázquez MA. A comparative study on the rhizomes essential oils of three Zingiber species from Manipur. Indian Perfumer. 2008;52:17-21.

44. Rana VS, Verdeguer M, Blázquez MA. Chemical composition of the essential oil of Zingiber zerumbet var. darcy. Nat Prod Commun. 2012;7:1369-70.

45. Ouattara ZA, Boti JB, Ahibo AC, Casanova J, Tomi F, Bighelli A. Analysis of Cleistopholis patens leaf and trunk bark oils using combined GC-Flame Ionisation Detection, GC-Retention Index, GC-MS and 13C-NMR. Phytochem Anal. 2013;24:574-80.

46. Mehl F, Marti G, Bocard J, Debrus B, Merle P, Delort E, Baroux L, Raymo V, Velazco MI, Sommer H, Wolfender JL, Rudaz S. Differentiation of lemon essential oil based on volatile and non-volatile fractions with various analytical techniques: A metabolomic approach. Food Chem. 2014;143:325-35.

47. Vail WB, Vail ML. Methods and apparatus to prevent, treat, and cure infections of the human respiratory system by pathogens causing Severe Acute Respiratory Syndrome (SARS). U.S. Patent No: 7,048,953; 2006.

48. Campbell B, Fernandez L, Huang H, Koivunen M, Marrone PG. Herbicidal composition for modulating growth or emergence of monocotyledonous or dicotyledonous weeds comprises lemongrass essential oil and carrier oil, non lemongrass essential oil or organic acid. Patent Number(s): WO2009049153-A2; US2009099022-A1; WO2009049153-A3; CA2701944-A1; 2009.

49. Sienkiewicz M, Kowalczyk E, Wasiela M. Recent patents regarding essential oils and the significance of their constituents in human health and treatment. Recent Pat Anti-Infect Drug Discov. 2012;7:133-40.

50. Chapin G, Wasserstrom R. Agricultural production and malaria resurgence in Central America and India. Nature. 1981;293:181-85.

51. Muller WH, Muller CH. Volatile growth inhibitors produced by Salvia species. Bull Torrey Bot Club. 1964;91:327-30.

52. Rice EL. Allelopathy, second ed. Academic Press, Orlando, Florida; 1984.

53. Putnam AR. Allelopathic chemicals: Nature’s herbicides in action. Chem Eng News. 1983;61:34-45.

54. Fischer NH. The function of mono and sesquiterpenes as plant germination and growth regulators, in The Science of Allelopathy, ed. by Putnam AR and Tang CS. Wiley, New York. 1986;203-18.

55. Fischer NH. Plant terpenoids as allelopathic agents, in Ecological Chemistry and Biochemistry of Plant Terpenoid, ed. by Harborne JB and Tomás-Barberán. Oxford: Clarendon Press. 1991;377-398.

56. Elakovich SD. Terpenoids as models for new agrochemicals, in Biologically active natural products-potential use in agriculture, ed. by Cutler HG. American Chemical Society, Washington, D.C. 1988;250-261.

57. Waller GR. Allelochemical action of some natural products, in Phytochemical Ecology: allelochemicals, mycotoxins and insect pheromones and allomones ed. by Chou CH and Waller GR. Institute of Botany, Academia Sinica Monograph Series No. 9, Taipei, Taiwan. 1989;129-154.
58. Macías FA, Galindo JCG, Castellano D, Velasco RF. Sesquiterpene lactones with potential use as natural herbicide models (II): Guaianolides. J Agr Food Chem. 2000;48:5288-96.
59. Macías FA, Molinillo JMG, Varela RM, Galindo JCG. Allelopathy - a natural alternative for weed control. Pest Manag Sci. 2007;63:327-48.
60. Langenheim JH. Higher plant terpenoids: A phytocentric overview of their ecological roles. J Chem Ecol. 1994;20:1223-80.
61. Tholl D. Terpene synthases and the regulation, diversity and biological roles of terpene metabolism. Curr Opin Plant Biol. 2006;9:297-304.
62. Dayan FE, Cantrell CL, Duke SO. Natural products in crop protection. Bioorg Med Chem. 2009;17:4022-34.
63. Grosso C, Coelho JA, Urieta JS, Palavra AMF, Barroso JG. Herbicidal activity of volatiles from coriander, winter savory, cotton lavender, and thyme isolated by hydrodistillation and supercritical fluid extraction. J Agric Food Chem. 2010;58:11007-13.
64. Scarfato P, Avallone E, Lannelli P, De Feo V, Acierno D. Synthesis and characterization of polyurea microcapsules containing essential oils with antigerminative activity. J Appl Polym Sci. 2007;105:3568-77.
65. Xiao Z, Liu W, Zhu G, Zhou R, Niu Y. A review of the preparation and application of flavour and essential oils microcapsules based on complex coacervation technology. J Sci Food Agric; 2013. (wileyonlinelibrary.com) DOI 10.1002/jsfa.6491.
66. Fernandes RVB, Borges SV, Botrel DA. Gum arabic/starch/maltodextrin/inulin as wall materials on the microencapsulation of rosemary essential oil. Carbohydr Polym. 2014;101:524-32.
67. Azirak S, Karaman S. Allelopathic effect of some essential oils and components on germination of weed species. Acta Agric Scand Sect B. 2008;58:88-92.
68. Asplund RO. Monoterpenes: Relationship between structure and inhibition of germination. Phytochemistry. 1968;7:1995-97.
69. Vaughn SF, Spencer GF. Volatile monoterpenes as potential parent structures for new herbicides.
70. Weed Sci. 1993;41:114-19.
71. Dudai N, Ben-Ami M, Chaimovich R, Chaimovitch D. Essential oils as allelopathic agents: bioconversion of monoterpenes by germinating wheat seeds. Acta Horticulturae. 2004;629:505-8.
72. Arminante F, De Falco E, De Feo V, De Martino L, Mancini E, Quaranta E. Allelopathic activity of essential oils from Mediterranean Labiatae. Acta Horticulturae 2006;723:347-52.
73. Vasilakoglou I, Dhima K, Paschalidis K, Ritzoulis C. Herbicidal potential on Loliun rigidum of nineteen major essential oil components and their synergy. J Essent Oil Res. 2013;25:1-10.
74. He HB, Wang HB, Lin ZH, Chen RS, Liu CH, Wu HW, Lin WX. Herbicidal effects of mixture of oxygenic terpenoids on paddy weeds. Allelopathy J. 2011;27:133-41.
75. He HB, Wang HB, Fang CX, Lin YY, Zeng CM, Wu LZ, Guo WC, Lin WX. Herbicidal effect of a combination of oxygenic terpenoids on Echinochloa crus-galli. Weed Res. 2009;49:183-92.
76. Mutlu S, Atici O, Esim N. Bioherbicidal effects of essential oils of Nepeta meyeri Benth. on weed spp. Allelopathy J. 2010;26:291-99.
77. Barton AFM, Dell B, Knight AR. Herbicidal activity of cineole derivatives. J Agric Food Chem. 2010;58:10147-55.
78. Angelini LG, Carpanese G, Cioni PL, Morelli I, Macchia M, Flamini G. Essential oils from Mediterranean lamiaceae as weed germination inhibitors. J Agr Food Chem. 2003;51:6158-64.
79. Vokou D, Douvli P, Blionis GJ, Halley JM. Effects of monoterpenoids, acting alone or in pairs, on seed germination and subsequent seedling growth. J Chem Ecol. 2003;29:2281-301.
80. Argyropoulos EI, Eleftherohorinos IG, Vokou D. In vitro evaluation of essential oils from Mediterranean aromatic plants of the Lamiaceae for weed control in tomato and cotton crops. Allelopathy J. 2008;22:69-78.
81. Morvillo CM, de la Fuente EB, Gil A, Martinez-Ghersa MA, González-Andújar JL. Competitive and allelopathic interference between soybean crop and annual wormwood (Artemisia annua L.) under field conditions. Eur J Agron. 2011;34:211-21.
82. Bainard LD, Isman MB, Upadhaya MK. Phytotoxicity of clove oil and its primary constituent eugenol and the role of leaf epicuticular wax in the susceptibility to these essential oils. Weed Sci. 2006;54:833-37.
83. Verdeguer M, Blázquez MA, Boira H. Germination inhibition of Amaranthus hybridus and Portulaca oleracea by Lantana camara L., Eucalyptus camaldulensis Dehn. and Eriophalus africanus L. extracts, in: 50 Years of the Phytochemical Society of Europe. Highlights in the Evolution of Phytochemistry. Abstract Book. Cambridge, UK. 2007;135-36.
84. Verdeguer M, García D, Blázquez MA, Boira H. Potencial alelopático de extractos acuosos de Lantana camara, Eucaliptus camaldulensis y Eriophalus africanus y posible uso como herbicidas naturales in Herbologia e Biodiversidade numa Agricultura Sustentável; Isa Press. 2009b;1:403-6.
85. Rosado LDS, Rodrigues HCA, Pinto JEBP, Custódio TN, Pinto LBB, Bertolucci SKV. Alelopatia do extrato aquoso e do óleo essencial de folhas do manjericão “Maria Bonita” na germinação de alface, tomate e melissa. Rev Bras Pl Med Botucatu. 2009;11:422-28.
86. Lee SY, Shim KC, Kil JH. Phytotoxic effect of aqueous extracts and essential oils from southern marigold (Tagetes minuta). New Zeal J Crop Hort Sci. 2002;30:161-69.
87. Dorman HJD, Deans SG. Antimicrobial agents from plants: Antibacterial activity of plant volatile oils. J Appl Microbiol. 2000;88:308-16.
88. Belaiche P. Traité de Phytothérapie et d’Aromathérapie, vol I (l’aromatogramme), vol II (Maladies infectieuses) Maloine, Paris; 1979.
89. Valnet J. Aromathérapie. Traitement des maladies par les essences de plantes. Maloine, Paris; 1980.
90. Valnet J, Duraffourd C, Duraffourd J, Lapraz C. L’Aromatogramme nouveaux resultants et essai d’interprétation sur 268 cas cliniques. Plant Méd Phytothér. 1978;12:43-52.
91. Zafra-Polo MC, Blázquez MA, Villar A. Spasmolytic and antimicrobial activity of the essential oils from Thymus leptophyllus and Thymus webbianus. Fitoterapia. 1989;60:469-73.
92. Bagamboula CF, Uyttendaele M, Debevere J. Inhibitory effect of thyme and basil essential oils, carvacrol, thymol, estragol, linalool and p-cymene towards Shigella sonnei and Shigella flexneri. Food Microbiol. 2004;21:33-42.
93. Devi KP, Nisha SA, Sakthivel R, Pandian SK. Eugenol (an essential oil of clove) acts as an antibacterial agent against Salmonella typhi by disrupting the cellular membrane. J Ethnopharmacol. 2010;130:107-15.
94. Lambert RJW, Skandamis PN, Coote PJ, Nychas GJE. A study of the minimum inhibitory concentration and mode of action of oregano essential oil, thymol and carvacrol. J Appl Microbiol. 2001;91:453-62.
95. Klein G, Rüben C, Upmann M. Antimicrobial activity of essential oil components against potential food spoilage microorganisms. Curr Microbiol. 2013;67:200-8.

96. Cherrat L, Espina L, Bakkali M, García-Gonzalo D, Pagán R, Laglaoui A. Chemical composition and antioxidant properties of Laurus nobilis L. and Myrtus communis L. essential oils from Morocco and evaluation of their antimicrobial activity acting alone or in combined processes for food preservation. J Sci Food Agric; 2013. (wileyonlinelibrary.com) DOI 10.1002/jsfa.6397.

97. Dussault D, Vu KD, Lacroix M. In vitro evaluation of antimicrobial activities of various commercial essential oils, oleoresin and pure compounds against food pathogens and application in ham. Meat Sci. 2014;96:514-20.

98. Kavanaugh NL, Ribbeck K. Selected antimicrobial essential oils eradicate Pseudomonas spp. and Staphylococcus aureus biofilms. Appl Environ Microb. 2012;78:5057-61.

99. Blázquez MA, Luciardi C, Cartagena E, Arena ME. Mandarin essential oil as natural antipathogenic agent in foodborne disease. Basic Clin Pharmacol Toxicol. 2013;113:8.

100. Scallan E, Hoekstra RM, Angulo FJ, Tauxe RV, Widdowson MA, Roy SL, Jones JL, Griffin PM. Foodborne illness acquired in the United States-major pathogens. Emerg Infect Dis. 2011;17:7-15.

101. Otto M. Quorum-sensing control in Staphylococci - a target for antimicrobial drug therapy? FEMS Microbiol Lett. 2004;241:135-41.

102. Shelef LA. Antimicrobial effects of spices. J Food Safety. 1983;6:29-44.

103. Fisher K, Phillips C. Potential antimicrobial uses of essential oils in food: Is citrus the answer? Trends Food Sci Tech. 2008;19:156-64.

104. Burt S. Essential oils: Their antibacterial properties and potential applications in foods: A review. Int J Food Microbiol. 2004;94:223-53.

105. Nostro A, Sudano Roccaro A, Bisignano G, Marino A, Cannatelli M A, Pizzimenti FC, Cioni PL, Procopio F, Blanco AR. Effects of oregano, carvacrol and thymol on Staphylococcus aureus and Staphylococcus epidermidis biofilms. J Med Microbiol. 2007;56:519-23.

106. Soni KA, Oladunjoye A, Nannapaneni R, Schilling MW, Silva JL, Mikel B, Bailey RH. Inhibition and inactivation of Salmonella typhimurium biofilms from polystyrene and stainless steel surfaces by essential oils and phenolic constituent carvacrol. J Food Protect. 2013;76:205-12.

107. Szczepanski S, Lipski A. Essential oils show specific inhibiting effects on bacterial biofilm Formation. Food Control. 2014;36:224-29.

108. Seydim AC, Sarikus G. Antimicrobial activity of whey protein based edible films incorporated with oregano, rosemary and garlic essential oils. Food Res Int. 2006;39:639-44.

109. Pelissari FM, Grossmann MVE, Yamashita F, Pineda EAG. Antimicrobial, mechanical and barrier properties of cassava starch-chitosan films incorporated with oregano essential oil. J Agr Food Chem. 2009;57:749-54.

110. Benavides S, Villalobos-Carvajal R, Reyes JE. Physical, mechanical and antibacterial properties of alginate film: Effect of the crosslinking degree and oregano essential oil concentration. J Food Eng. 2012;110:232-9.

111. Ojagh SM, Rezaei M, Razavi SH, Hosseini SMH. Development and evaluation of a novel biodegradable film made from chitosan and cinnamon essential oil with low affinity toward water. Food Chem. 2010;122:161-66.

112. Sánchez-González L, Cháfer M, Chiralt A, González-Martínez C. Physical properties of edible chitosan films containing bergamot essential oil and their inhibitory action on Penicillium italicum. Carbohyd Polym. 2010;82:277-83.
113. Gómez-Estaca J, López de Lacey A, López-Caballero M, Gómez-Guillén M, Montero P. Biodegradable gelatin-chitosan films incorporated with essential oils as antimicrobial agents for fish preservation. Food Microbiol. 2010;27:889-96.

114. Abdollahi M, Rezaei M, Farzi G. A novel active bionanocomposite film incorporating rosemary essential oil and nanoclay into chitosan. J Food Eng. 2012;111:343-50.

115. Alboofetileh M, Rezaei M, Hosseini H, Abdollahi M. Antimicrobial activity of alginate/clay nanocomposite films enriched with essential oils against three common foodborne pathogens. Food Control. 2014;36:1-7.

116. Peng Y, Li Y. Combined effects of two kinds of essential oils on physical, mechanical and structural properties of chitosan films. Food Hydrocolloid. 2014;36:287-93.

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