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Scientific Findings: The Amazing use of Essential Oils and their Related Terpenes as Natural Preservatives to Improve the Shelf-Life of Food

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Abstract

There is growing legislation against the use of synthetic and chemical food preservatives as antimicrobials. Therefore, it is essential to discover and develop alternative safe and natural techniques for controlling food-borne and spoilage bacteria, fungi and yeast in and through food. Worldwide studies carried out on essential oils (EOs) have motivated scientists to focus their interest toward the research of botanical antimicrobials. It is obvious that the application of EOs and their derivatives has been widely described and used against a wide range of food-borne and food spoilage microorganisms. Research on the use of EOs as natural preservatives in the food industry is still in the "childhood" step with more exciting and promising discoveries to come. Still, the findings are extremely encouraging and suggest that EOs or their characteristic chemical compounds (thymol, carvacrol, linalool, citral, citronellol, geraniol, eucalyptol, geranyl acetate and limonene) can replace chemical food preservatives and create all-natural, safe, and tasty food products with a long shelf-life.

Keywords: Natural Food Preservative; Essential Oils; Aromatic Herbs and Spices; Food Spoilage Microorganisms; Food Shelf-Life

Introduction

The modern food industry has progressed into a complicated organization. Raw materials of food are cultivated in one part of the globe, transported into another area to be prepared as fruit juices, and are sold into yet another completely different region. This extended chain that links producers to customers will not be able to function if we can't discover and develop a method to provide our food crops longer shelf-lives [1].

Food safety scientists, regulatory agencies and food processors have been progressively worried with the rising cases of food-borne disease and infection outbreaks linked to microorganisms and pathogens such as *Salmonella* sp., *Campylobacter*, *Staphylococcus aureus*, *Vibrio parahaemolyticus*, entero-pathogenic *Escherichia coli*, *Clostridium perfringens*, *Candida albicans*, *Aspergillus niger*, *Bacillus cereus* and *Listeria monocytogenes* [2,3]. These bacteria and fungi cause over 90% of all cases of food infections. Poisoning due to bacterial, yeast and fungal strains also remain a considerate clinical problem. In addition, emerging resistance of microorganisms (multi-drug resistant bacteria) is extremely reducing the number of active antibiotics and antimicrobials [3-5].

Food preservatives have been used for thousands of years. According to historical annals, human beings have been looking for sure, nontoxic and long-term conservation of food. Food preservatives used in human history are spices, aromatic herbs, sugar, salt and vinegar, while new food preservatives are chemical molecules such as nitrates, benzoates, sorbic acids and sulfites. However, safety of most of these chemical additives is reasonably questionable. There is increasing public anxiety among consumers concerning the adding of food chemical additives to foods [6].

Particular examples comprise the application of synthetic preservatives (antioxidant and antibacterial) that have been regularly used to improve shelf-life of several foods. For example, in the USA and most of the European countries, the poultry and meat industry have relied heavily on synthetic antioxidants, including TBHQ (tert-butylhydroquinone), BHT (butylated hydroxytoluene), BHA (butylated hydroxyanisole) and PG (propyl gallate), as well as vitamin E (tocopherols) and vitamin C (ascorbic acid) to prevent protein and lipid oxidation [7-9].

Nevertheless, BHA is designated as a carcinogen. Also, the addition of BHT into the diet considerably augmented the frequency of liver cancers in animals [10]. Other investigations have also revealed that BHT can cause lung (pulmonary) irritation and inflammation [11]. There is continuing studies funded by the National Institute of Environmental Health Sciences on the potential relationship between the synthetic additives and food allergies [12].

A remarkable British study, in The Lancet, establishes that sodium benzoate used as a food preservative posed too much of a danger for hyperactivity in children to go ignored. Until now, the U.S. Food and Drug Administration (FDA) still consider this molecule harmless when "correctly" used [13]. The same goes for about more than 45 other synthetic food preservatives and additives comprising monosodium glutamate (MSG), potassium nitrate and sodium nitrate, aspartame, sodium benzoate and citric acid (E300). Common food additives have been associated to human health problems and are no longer trusted by consumers [14].

Despite growing, placebo-controlled, double-blinded evidence demonstrating the side effects and negative physiological influences of most synthetic food additive ingredients, the FDA continues to ignore the injurious effects of numerous, conventionally-produced food preservatives.

Consequently and because of growing pressure of legal authorities and customers, the food industry has a tendency to diminish the application of chemical food additives or to search for more safe and natural substitutes for the extension or maintenance of food shelf-life [15-20]. Food companies are also actively looking for additives from natural sources which have safe and effective molecules with improved food shelf-life and delayed food deterioration [21-23].

Therefore, one of the major emerging technologies is the application of essential oils (EOs) to foods [21,23-26]. For example, EOs have received growing consideration as natural food preservatives for the shelf-life improvement. The chemical composition of EOs revealed the presence of several bioactive molecules, which have antibacterial, antifungal and antioxidant activities *in vitro*, so their use can be very beneficial to improve food shelf-life [27,28]. Gratefully, there are researchers and scientists that say 'move over synthetics' because they've discovered how to harness EOs as a healthy and safe food preservative [29-31].

All you Need to Know about Essential Oils

EOs, also named volatile odoriferous oil, are scented oily liquids obtained from different parts of aromatic herbs and medicinal plants (flowers, peels, stems, leaves, buds, barks and seeds) (Figure 1). They can be distilled from botanical materials by different techniques such as hydro- or steam distillations, cold expression method, solvent-free microwave extraction assay, supercritical fluid extraction technique, and so on. Among all these methods, steam distillation has been extensively used, particularly for commercial scale production [32,33].

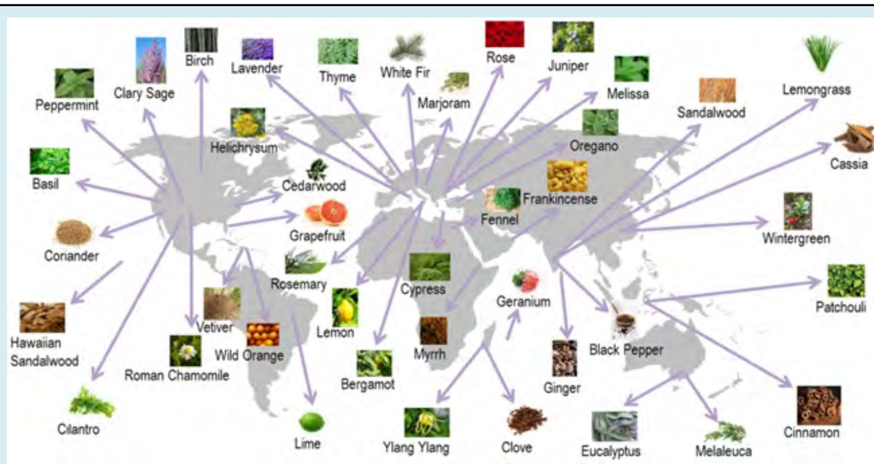

Figure 1: Essential Oils around the World.; (Source: www.doterra.com; updated: 04 March 2020, 14:00 GMT)

Steam distillation is a technique used for the recovery of volatile or aromatic chemical constituents with high boiling point, from inert and complex matrices, liquid or solid, using saturated or superheated steam as separation and energy agent. This method is used for the extraction of EOs from aromatic herbs, spices and medicinal plants. Steam distillation (Figure 2) is done by passing dry steam through the aromatic herbs and plant material whereby the steam volatile molecules are volatilized, condensed and obtained in receivers. Steam distillation has been in use for EO extraction for many decades. Hydrosteam distillation is done when the aromatic herbs and the perfumery plant material is susceptible to direct steam. In this method the plant material is supported on a screen or a perforated grid placed at some distance above the bottom of the still. Distillation is realized with low pressure steam which replaces the volatile compounds from the intact aromatic plants. In this method, two different products are obtained: EO and hydrosol (aromatic water). The EO is in the upper phase and the aromatic water (water and some hydrolyzed molecules) is in the bottom phase of the decanter. Steam-distillation has been used for a many years to extract dairy aromas from dairy products. Nevertheless, great temperatures may affect the composition and the quality of the aroma obtained, because of degradation of heat-sensitive flavor molecules. Another main disadvantage is that hydrophobic flavor components may be retained by the matrix of the original plant, leading to a changed composition of the aroma. As steam distillates contain a significant quantity of water (up to 90%), a weak aroma is obtained [32-35].

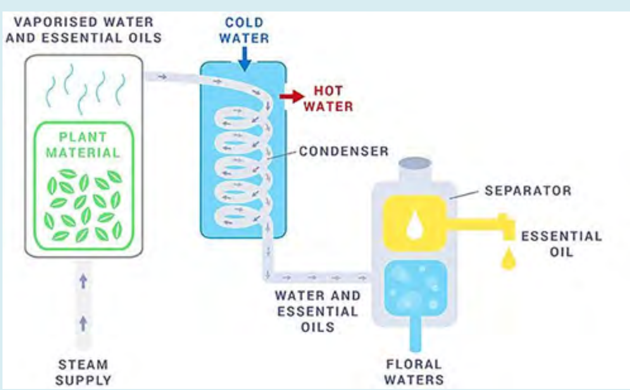

Figure 2: Extraction of essential oils from perfumery plant material using the steam distillation technique.
(Source: www.essentialoilmach.com/news ; updated: 17 March 2020, 10:00 GMT)

Cold pressing (Figure 3) is a mechanical extraction process of EOs, also known as expression or mechanical separations. Cold-pressed EOs from the peel are the first by-products to be recovered during the processing of *Citrus* fruits and any improvement in their recovery is of great interest for the *Citrus* processing industry. It is typically used to extract *Citrus* EOs. In this technique, the oil is forced from the material under high mechanical pressure. Many base oils are obtained in the same way.

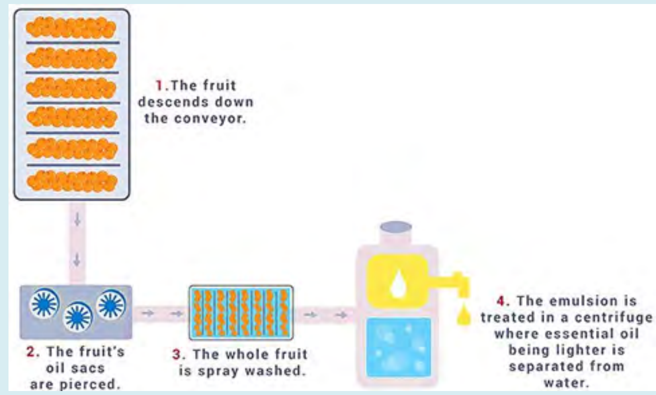

Figure 3: Cold-Press extraction used for citrus peels.
(Source: www.essentialoilmach.com/news ; updated: 17 March 2020, 10:00 GMT)

Novel equipment's have been constantly established to overcome the limitation and inadequacy of traditional techniques, and to improve the distillation effectiveness [34,35].

EOs found in several aromatic herbs differ in flavor and odor, which are influenced by the quantity and types of chemical compounds present in EOs. EOs are unique because they offer such an extensive spectrum of uses. Actually, as many as 3,000 EOs are of commercial significance in current industries ranging from beverages and food to pharmaceuticals and cosmetics [35]. The food manufacturing has become particularly involved in approving EOs to satisfy consumer demands [17,23,34].

EOs have been recognized to have antimicrobial and antioxidant properties, thereby serving as natural food preservatives. Further, EOs may be able to be used as food additives in packaging to improve the food shelf-life, in which the characteristics of those materials, mainly water vapor barrier property linked with hydrophobicity in nature of EOs, can be enhanced [36-38].

In Vitro Antimicrobial Activity of EOs against Food Spoilage Microorganisms

Aromatic herbs and their EOs are possibly valuable sources of antibacterial and antifungal chemical molecules. Several reports and investigations have been done and published on the inhibitory effects of EOs and their characteristic compounds against different types of microorganisms, including food-borne and spoilage pathogens [39-41]. Due to these properties, aromatic herbs and spices have been added to food since antique time, not only as condiments or flavoring agents but also as preservatives [23,26,29,42]. Furthermore, essential oil-rich aromatic plants and spices have usually been used in Chinese, Indian, Middle Eastern, Indian, and African cuisines to stimulate digestion and enhance food taste [15,21,23].

The principal chemical constituents of EOs - mono- and sesquiterpenes including phenols (thymol, carvacrol and eugenol), ethers (eucalyptol), esters (geranyl acetate and citronellyl formate), aldehydes (cinnamaldehyde, citral, geranial and neral), ketones (carvone and menthone), alcohols (citronellol, geraniol, linalool and menthol) and carbohydrates (limonene and pinene) (Figure 4) are responsible for the *in vitro* antimicrobial and antioxidant activities of medicinal plants and aromatic herbs as well as for their EOs [16,34,35,37,43]. Also, the minor compounds of EOs have revealed that they play a significant role against fungal and bacterial species. It can be probably due to the synergy effect when combined with major chemical compounds as it occurs in rose-scented geranium, lemongrass, thyme, sage, lavender, oregano and eucalyptus [23,34,35,38,44]. Moreover, numerous EOs and their constituents are stated by the U.S. FDA to have a GRAS (Generally Recognized As Safe) status and are approved as aroma or food additives [21,23].

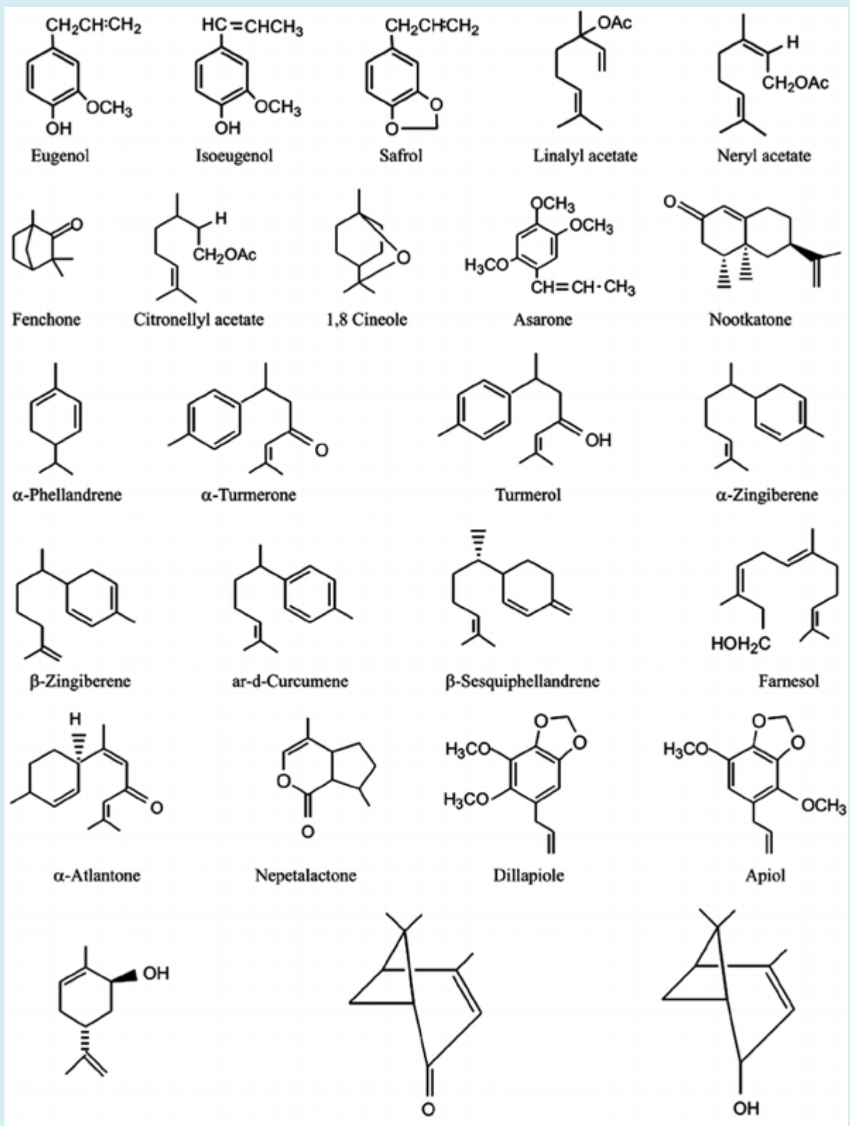

Figure 4: Chemical structures of essential oil constituents.

Currently, scientists are studying EOs as many of them have antimicrobial activities and are powerful antifungal and antibacterial agents. Several EOs proved powerful and potent *in vitro* antibacterial and antifungal effects that have the ability to serve as natural additives against food-borne and spoilage species [18,45-47].

The antibacterial activities of botanical EOs have been known for a long time and a number of researches on the antibacterial effect of plant essential oils and their derivatives have been reported by different investigations [44,46]. For example, the microbial inhibitory effect of EOs and major compounds has been reported on *Escherichia coli* and *Escherichia coli* O157:H7 [47-49].

When comparing results obtained in different publications, most authors give an overview about whether or not plant EOs or major compounds have antibacterial and antifungal effects against Gram-negative or Gram-positive bacteria, yeast and fungi. However, not all studies describe detail about the extent or spectrum of this inhibitory effect. Primarily, the difference in the microbial inhibitory effect of EOs or chemical compounds between different publications may be linked to the diverse environmental growth condition and growth stage of aromatic herbs and medicinal plants, extraction techniques, chemical composition of EOs, microbial strains and species used and storage temperature [19,27,50-52]. Additionally, some EOs with the same common name may be derived from diverse botanical species. Moreover, the technique used to assess *in vitro* antibacterial and antifungal activities and the choice of test microorganism (s) varies between research articles [20,53-60].

How Efficient are Essential Oils as Preservatives in Foods?

Research into the efficacy of EOs or their major compounds in the preservation of food commodities in order to increase shelf-life has been efficaciously carried out. Several articles on the antioxidant and antimicrobial properties of EOs in food recommend their use to improve food safety [26,27,29,39,61].

The use of EOs for shelf-life improvement in foods is mostly due to their antibacterial, antifungal and antioxidant effects which also is mirrored in the number of research articles published when the words "antimicrobial" (344,000 papers), "antibacterial" (244,000 Papers), "antifungal" (144,000 papers), "antioxidant" (418,000 papers), or both (162,000 papers) were used as searching criterion in google scholar website. Regarding the type of food systems generally used in these investigations, it can be concluded that EOs or chemical compounds have been applied as natural preservatives in all kinds of foods: fish products (70,500 papers), meat products (61,300 papers), milk and dairy products (40,100 papers), fruits (63,000 papers), vegetables (56,100 papers), fruit juices (33,700 papers) and bread and baked foods (27,500 papers).

Furthermore, scientists have used EOs, either in pure or formulation forms, to improve food shelf-life in several storage containers such as those made of cardboard, tin, glass, polyethylene, or natural fabrics and have observed important extension of food shelf-life [62,63].

Kim & Fung [64] reported inhibitory effects of *Puerariae radix* in ground beef and especially liquid foods like mushroom soup on *Escherichia coli* O157:H7. An earlier study demonstrated that some EO chemical compounds such as citronellal, citral, farnesol, citronellol, geraniol, eucalyptol, nerol, thymol and eugenol, and could protect chili seeds and fruits from fungal infection for up to 6 months [62]. Another study revealed that EO from *Ageratum conyzoides* effectively controlled rotting of mandarins by blue mold and increased mandarin shelf-life by up to 30 days [65]. It has been reported also that EO from *Ocimum basilicum*, *Cymbopogon nardus* and *C. flexuosus* could significantly control anthracnose in banana and increased banana shelf-life by up to 21 days [66]. Also, *Cymbopogon flexuosus* EO (20 μL/mL) is capable of protecting against rotting of *Malus pumilo* fruits for up to 3 weeks [67].

A fumigant application of EOs from *Putranjiva roxburghii* was effective against *Aspergillus flavus* and *A. niger* infecting groundnuts during storage and improved the shelf-life of groundnut from fungal contamination for up to 6 months [68]. The use of *Cymbopogon pendulous* EO as a fumigant increased groundnut shelf-life by 6-12 months [69], thus proving to be more effective than *Puerariae roxburghii* EO.

A small incorporation of oregano EO (up to 1% v/w) to ground meat was revealed to delay bacterial growth [29], while its addition to beef meat fillets contaminated with *Listeria monocytogenes* eliminated these harmful bacteria [70]. Further, several investigations have demonstrated that an addition of oregano EO to apple juice and eggplant salad [71] contaminated with *Escherichia coli* suppressed growth of these microorganisms [30].

Citrus EOs, such as lemon (*Citrus limon*), sweet orange (*Citrus sinensis*), and bergamot (*Citrus aurantium* var. *bergamia*) are cold-pressed from the citrus fruit peels. These EOs are rich with limonene, a hydrocarbon monoterpene that is a strong antimicrobial agent. Citrus EOs suppress growth of many bacteria that can cause food poisoning [72]. They are very active antimicrobial agents when added to bread and mozzarella cheese [73].

In some cases, the natural EO compounds performed even better than the synthetic food preservatives [57-59,74]. These differences in efficacy of EOs may be related to the use of oils from different plant species, as well as to their chemical composition, dose level, and storage container type [20,25,34,54].

Active Packaging Containing Essential Oils and Applications

Nowadays, smart packaging has gained increasing attention, for example, antimicrobial packaging, which can be applied to extend the shelf-life of food and products [75,76]. To enhance the property of those packaging, antimicrobial compounds or phytochemical extracts with the selected bioactivity are incorporated. Thus, several approaches have been introduced, not only for increasing bioactivity but also modifying the property of biomaterials used for packaging [77-79].

EO integration into food packaging may increase water vapor barrier properties of protein-based films, improve the strength of the film and resistance to stretching, decrease transparency, and help prevent food contamination by interacting with the films [80,81].

A new research in the Journal of Food Science, published by the Institute of Food Technologists (IFT), revealed that EOs may be able to be used as natural food preservatives in packaging to help improve the shelf-life of food products [82].

The films that were used in a recent 2014 research published in the Journal of Agricultural and Food Chemistry containing oregano and clove oil were able to preserve bread longer than common commercial additives. Bread was chosen given its global popularity as a food-stuffs mainstay. The films were tested after 10 days and the EO used, as a food preservative, were shown to slow mold growth [83-94]. EO films could offer widespread application, reducing food waste while slowing the production of synthetic additives. Reducing chemical food additive and preservative production offers a positive environmental impact by decreasing pollution that results from the manufacturing process as well [95-97]. One possible method to achieve this is to add EO combinations to edible fibers and to coat the surface of food products - such as cheese, bread, and fruits - creating edible films. These films protect freshness and prevent growth of pathogenic bacteria. Edible films containing a combination of clove *Syzygium aromaticum* and oregano *Origanum vulgare* [83] and a combination of rosemary (*Rosmarinus officinalis*), oregano (*Origanum vulgare*) and garlic (*Allium sativum*) [85] EOs were found to be particularly effective.

Limitations

Although EOs have been demonstrated to be favorable substitutes to synthetic food additives, they have several restrictions and limitations that must be resolved before their use in a real food matrix. High volatility and instability, low water solubility, and strong scent are the principal properties that make it problematic for food uses [20,24,25,54]. Modern progresses that refer to novel and promising forms of addition to decrease these difficulties are presently under investigation. Their potential use into coated films and packaging materials, but also directly into the food systems as nano-encapsulation (Figure 5) and coating are some of their different uses among others [55].

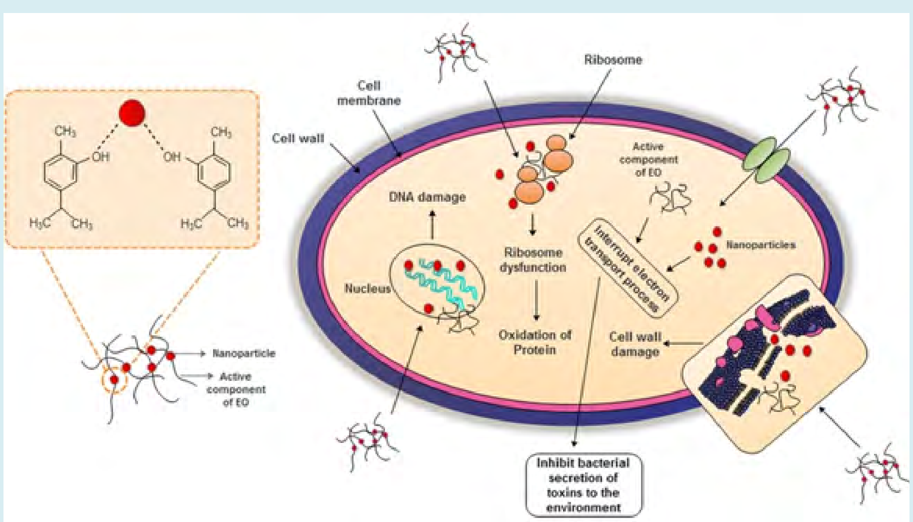

Figure 5: Schematic representation of possible mechanism of actions nano-encapsulated Eos [93].

Although the majority of the botanical EOs are recognized as GRAS [26,34], their application as food preservatives is limited, and possible reasons for this limitation may be the strong flavor and scent of these natural molecules when used at active concentrations and the reduction in their efficiency when they are incorporated to complicated food systems [29] in comparison with microbiological media [56-58]. For this reason, there is a growing request for exact data of the minimum inhibitory concentrations (MIC) and minimum bactericidal or fungicidal concentrations (MBC, MFC) of EOs to allow equilibrium between the antimicrobial efficiency and sensorial or organoleptic acceptability [59] in different systems. For example, doses of Oregano EO as low as 0.7% seemed to be microbiologically effective and organoleptically acceptable as well. The Addition of EOs is therefore not problematic, especially not when used in such a small amount as we define according to the MIC and MBC values [60]. Furthermore, a recent investigation reported that EO extracted from oregano can maintain the physico-chemical, sensory acceptance, decrease protein and lipid oxidation of lamb meat after freezing storage after 120 days [60]. These data suggest that that oregano EO may be a potent alternative to the chemical food preservatives.

Synergistic Preservative Effects

The antimicrobial effect of EOs in model food matrices or in real food is well documented in the literature [30,70,85]. Several reports are focused on the synergistic action of EOs. Scientists are working for the combinations of EOs that will make them active against a wide spectrum of bacteria, yeast and fungi; combine both antioxidant and antimicrobial effects; and allow the EOs to accomplish the desired effects with the minimal concentration [20,34,86].

Application of EOs is mainly advisable because spices and aromatic herbs are usually added in food to obtain a specific flavor and taste. Adding different plant derived antimicrobials or EOs in combination should increase both the antimicrobial spectrum of activity and the level of inhibition due to synergistic effects. Thus, the combination of EOs and their chemical compounds might have even greater potential [87,88]. Due to the growing consideration in natural food additives, EOs have been used more extensively, particularly in combination with other preservations under the concept of "hurdle technology."

Oregano EO was studied as an alternative natural additive and found to contribute to the intrinsic safety of eggplant salad, acting synergistically with low pHs and storage temperatures [30]. When associated with balanced portions of safe chemical preservatives, the synergistic effect between EOs and synthetic preservatives is even more powerful. This gives food manufacturers a promising way to compromise between the undeniable necessity to maintain food safety and the desire for natural ingredients [89,90].

Further, it has been revealed that the use of thermal processing affects the aromatic compounds such as EOs by increasing their vapour pressure, which in turn increases the probability to solubilize the bacterial and yeast cell membrane (Figure 6). Though, the application of only one preservation treatment cannot guarantee the microbial stability of foods and beverages without disturbing the final sensorial and organoleptic properties. The association of moderate heat treatment with EOs (Mentha, Lemongrass (*Cymbopogan citratus*) and Eucalyptus) gives a very valuable and suitable synergy whereby increase in temperatures during storage could improve the vapour phase concentration of EOs, thereby enhancing the antifungal and antibacterial properties for better food or beverage preservation [56-58,91]. This synergistic association can be used as a superior preservative with minimal impact on the sensory properties of the food and beverage.

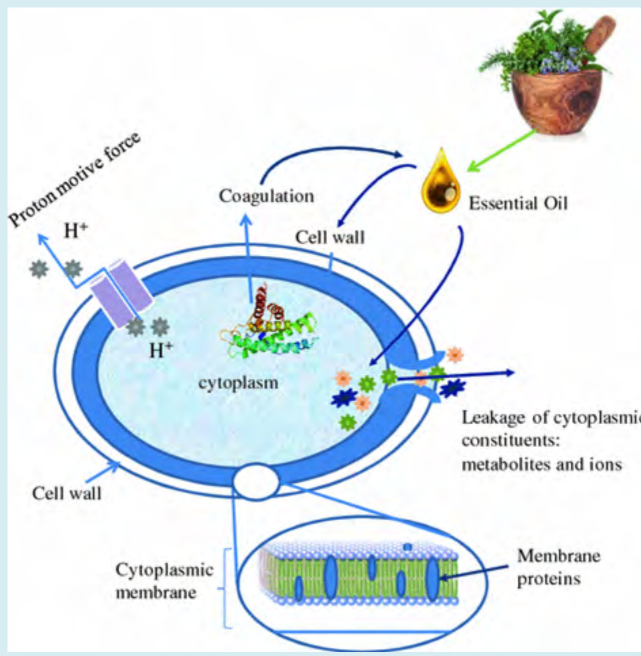

Figure 6: Antimicrobial action mechanism of EOs[91].

Conclusion

The interest in EOs and their related terpenes for potential application in food preservation has been augmented in a last decade by an increasingly negative consumer perception of chemical and synthetic food additives. The use of chemical additives and synthetic preservatives and is leading to cancer, inflammation, intoxication and other degenerative diseases. Additionally, food-borne and food spoilage microorganisms are a growing human health concern worldwide, calling for more potent preservation approaches. One of the major emerging technologies for food preservation is the application of EOs and their characteristic purified molecules. EOs and related terpenes have received growing consideration as natural food preservatives for the shelf-life improvement. They have in vitro antimicrobial activity against a wide range of bacteria, fungi and yeast as well as antioxidant property, which is generally attributed to phenolic compounds and oxygenated monoterpenes owned by EOs. Mediterranean dietary food products are greatly appreciated by consumers; their natural preservation with EOs would represent an added value. As EOs contain a large number of molecules, it is expected that their mechanism of action includes numerous targets in the microorganism's cell. However, the main obstacle for using EO constituents as food preservatives is that they are most often not active enough as single molecules, and they cause negative sensorial and organoleptic effects when used and added in sufficient quantities to provide an antibacterial and antifungal activities. Further, it must be taken into account that EOs have a strong flavor and odor, which can change the flavor and scent of food products. Consequently, investigations should focus on the minimum necessary EO concentration, which still maintains microbial inhibitory effect without altering the organoleptic properties of food products. In addition, the combined use of different EOs or related terpenes, in lower doses, may satisfy the quality and safety of food products not depreciating their sensory characteristics.

Conflicts of Interest

The author declares no conflict of interest.

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