Essential Oils for Food Packaging

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Definition

Essential oils (EOs) are concentrated liquid mixtures of volatile compounds with antioxidant and antibacterial properties that can be used as natural, eco-friendly, renewable, and cost-effective additives. The use of combinations of different EOs and their components is a promising strategy to increase the synergistic and additive effects of EOs in foods.

1. Introduction

Microbial food spoilage and oxidative deterioration during the storage of foods are major concerns for our society. Pathogenic microorganisms, including bacteria and fungi, spoil perishable foods, such as fruits, vegetables, fish, meat, poultry, and fresh cereal-based products, and generally cause changes in flavor, texture, color, odor, and taste [1]. In addition, enzymes, air, light, and temperature cause changes in color, texture, and flavor, and reduce the shelf life of foods, thereby increasing the risk of foodborne illness. As a result, artificial or synthetic preservatives have been used by the food industry for many years. These artificial preservatives are chemical substances such as nitrites, benzoates, propionates, and sorbates, which destroy bacteria or inhibit the growth of mold on foods. Similarly, sulfites, tocopherol, ascorbic acid, butylated hydroxyanisole, and butylated hydroxytoluene are antioxidants that inhibit oxidation and disodium ethylenediaminetetraacetic acid, citric acid, and polyphosphates are chelating agents that can slow down or restrict the deterioration of food [2]. However, it is very important for consumers to be aware of some synthetic preservatives that are toxic, carcinogenic, and commonly used at high concentrations [3]. Thereby, it is essential that consumers purchase safer, high-quality, natural, and less processed foods that are free from synthetic preservatives and have extended shelf lives. This situation has motivated scientists to explore natural alternatives to chemical or synthetic food preservatives.

Packaging systems play a primary role in containing and adequately protecting food products as they move through the supply chain to the consumer. The use of proper packaging methods and materials to maintain/provide high quality, superior taste, fresh, safe, and convenient food products have constantly increased in recent decades [4]. In addition, packaging meets the fundamental need to extend the shelf life of food by preventing unwanted chemical and biological changes from production to final consumption. Consequently, changes in retail practices, globalization of markets, centralization of activities, and longer transport distances have become major challenges for food packaging industries in designing supply chains and moving food products to consumers [5]. The main function of packaging is to provide passive protection to the products or act as a barrier between the food, atmosphere, and the external environment [6]. Some properties of the additives with active functions in food packaging systems include absorbing/scavenging properties (additives include moisture, oxygen, carbon dioxide, ethylene, flavors, and UV light); releasing/emitting properties (e.g., antioxidants, preservatives, sulfur dioxide); removing properties (e.g., lactose and cholesterol); and temperature, and microbial control [7].

Among natural antimicrobials, EOs have been widely used as food flavors because of their antibacterial, antifungal, antioxidant, antiseptic, anti-inflammatory, anticarcinogenic, and antimutagenic properties. EOs are liquid mixtures of volatile and hydrophobic compounds obtained from different parts of aromatic medicinal plants, such as leaves, buds, flowers, shoots, peels, barks, twigs, fruits, seeds, and roots. They provide the essence of the plant with specific odoriferous and lipophilic characteristics, which are responsible for the aroma and flavor of spices [8]. Currently, approximately 3000 varieties of EOs are well known, of which approximately 300 are commercially important in the flavor, fragrance, pharmaceutical, food, and cosmetic industries [9]. Moreover, it is well known that plants produce a wide variety of secondary metabolites with remarkably low boiling points that influence the oxidative stability of EOs and have good antioxidant properties to protect food from rancidity [10]. EOs are secreted by specialized secretory plant tissues called glandular trichomes, which are multicellular epidermal glands that diffuse onto the surface of plant organs, particularly leaves and flowers [11]. EOs secreted by trichomes are a mixture of several low molecular weights (<300 Da) and other volatile compounds, including terpenoids, phenylpropanoids, isoprenoids, phenols, alcohols, and aldehydes [11].

The amount of EOs varies among different components, parts of plants, and plant species, and this determines the price of EOs. The main EOs responsible for antimicrobial and antioxidant properties are thyme, lemon, clove, cinnamon, and tea tree oils, which effectively increase the quality and shelf life of food and other cereal products [12]. The antimicrobial action of EOs is mainly a consequence of their hydrophobic nature, which enables them to partition into the lipid layer cell membrane and mitochondria, providing them with greater permeability, causing damage and disrupting the cell wall structures [13]. Thus, EOs are promising alternative compounds to serve as natural additives, preservatives, and active packaging systems in food and food products to reduce the existing problems associated with food safety risks from chemically synthesized additives [14].

2. Role of Essential Oils in Active Food Packaging Applications

EOs are widely used as natural additives to prolong the shelf-life of food and ensure food safety and quality in a sustainable manner. Nowadays, the demand for smart or active packaging in the food processing industry is growing mainly due to the extension of the shelf life of packaged food products and the prevention of food from spoiling. Many investigations have been conducted using either pure Eos or formulations of Eos in different storage containers, such as tin, glass, cardboard, and polyethylene, and significant improvements have been observed in their shelf lives. The major components of Eos are potential antimicrobials and antioxidants applied in most common types of food such as fruits, vegetables, meat, fish, dairy products, bread, and bakery foods [15]. Eos may quickly decompose or degrade because of their unstable volatile constituents when applied directly to the food matrix. The stability of Eos depends on many extrinsic and intrinsic factors that lead to chemical reactions. The extrinsic factors include the presence of oxygen, exposure to light, temperature, and humidity, whereas the intrinsic factors include the chemical structure and impurities present in Eos [16].

Thus, several promising approaches have been introduced to improve and enhance the stability of Eos by encapsulating them with polymers, liposomes, and solid lipid nanoparticles. Generally, the selected packaging (biopolymer) film matrix incorporated with Eos is prepared by the casting method, in which films are dispersed in casting solution followed by evaporation of the solvent [17]. Analyses of the optical, mechanical, and barrier properties of the active films are essential to aid their choice for use in different food matrices. Analysis of the mechanical properties, including tensile strength, breaking strength, and elastic modulus of the polymer film matrix is essential. Similarly, analysis of the chemical and physical properties, such as solubility, thickness, water activity, thermogravimetry, and permeability of water vapor, oxygen, and carbon dioxide, in the film matrix is required to ensure the quality and safety of food [17]. Cinnamon, thyme, oregano, jasmine, rosemary, cumin, peppermint, tea tree, clove, eucalyptus, geranium, lemon, mandarin, rosewood, lavender, lemongrass, and palmarosa are the most commonly used EOs, together with their constituents, in packaging systems.

Several authors have reported the potential of EOs to improve the quality and safety of food and extend the shelf life of such products [18]. The best results were achieved when oregano and clove EOs were incorporated into cassava bagasse-polyvinyl alcohol (PVA), resulting in the inhibition of, or reduction in, total microbial viability, including molds, yeasts, and both gram-positive and gram-negative bacteria [19]. In another study, thyme EO encapsulated with curdlan-PVA showed improvement in antioxidant activity and extension of the shelf life of chilled meat [20]. Similarly, rosemary EO encapsulated with whey protein isolate/cellulose nanofiber film increased the shelf life of lamb meat for up to 15 days when compared to the control meat after 6 days [21]. Citral and eugenol EOs with sodium alginate are capable of protecting against microbial growth and improving the postharvest quality of strawberry fruits [22]. Similar results were observed with citronella, lemongrass, and basil EOs, which could significantly control crown rot, anthracnose, and increased banana shelf life with texture and flavor [23].

In fact, foods are more susceptible to oxidation; thus, the most common cause of food spoilage is oxidative rancidity and microbial growth. However, packaging films loaded with different EOs showed a better antioxidant capacity for DPPH, FRAP, and ABTS assays. For instance, edible pectin film with cinnamon EO increased the antioxidant capacity and reduced the bacterial growth of fresh-cut peaches [24]. The shelf life of fresh Mediterranean swordfish increased for up to 13 days when treated with thyme EO with low-density polyethylene [25]. Similarly, chitosan/montmorillonite incorporated with rosemary EO extended the shelf life of poultry meat for 15 days [26]. The higher antioxidant effects of oregano EO incorporated with soy protein film resulted in ground beef patties that control primary lipid oxidation and lipid hydrolysis [27]. Thyme is one of the most potent antioxidants, followed by rosemary, which could be due to their chemotypes and a high percentage of terpenes. Hence, EOs should be considered as potential antioxidants based on the evidence presented in these reports.

3. Synergistic Advantages of Different Essential Oils

Multidrug-resistant bacteria are considered one of the most significant emerging threats to human health worldwide. Therefore, there is an urgent need to find alternative strategies to prevent and treat bacterial infections resulting from MDR bacteria with new structures and novel mechanisms. A combination or interaction between different EOs and their major or minor constituents may lead to additive, synergistic, or antagonistic effects [9]. An additive effect is generally considered as the combined effect of two or more compounds being equal to the sum of individual effects. Synergy is defined as the combined effect of two or more compounds that is greater than the sum of the individual effects. An antagonistic effect is observed when the effects of two or more substances in combination are lesser than the sum of the individual effects of those substances. Synergy is a pillar of modern pharmacology and medicine, because many diseases require treatment that consists of a mixture or combination of various drugs or antimicrobials taken at once [28]. Synergistic interaction enhances the antimicrobial and antioxidant activities by employing the combination of two or more EOs in the best possible manner, thereby reducing the required doses of the combined agents. This potentially benefits patients for the treatment of the disease, while minimizing side effects and adverse reactions [29].

The antioxidant and antibacterial activities of different EOs may depend on one or two of the major constituents of the oil. Compared to the use of a single EO or compound, the combination of two or more EOs or their constituents can improve their antimicrobial activities, preservative effects, and reduce organoleptic impact in food even at lower doses. A mixture of two or more EOs can increase the diversity of components and result in multiple sites of action. There has been an increasing demand for synergistic effects of EOs and their constituents due to their multiple biochemical processes and interactive antibacterial effects in food preservation [30]. Interestingly, combinations of phenylpropanoid (eugenol and chavicol) and phenolic monoterpenes (thymol and carvacrol) with other components were found to increase bioactivities, including antimicrobial, antioxidant, antiherbivore, and other pharmaceutical activities. For instance, the combination of phenolics with monoterpene alcohols exhibited the highest synergistic effect against E. coli pathogens [30]. Another study revealed that the binary combination of carvacrol and thymol and the ternary combination of carvacrol, thymol, and eugenol had the most synergistic effect against L. innocua [31].

Antioxidant and antibacterial evaluation of different herbs and spices such as cumin, coriander, black pepper, garlic, ginger, onion, turmeric, bay leaf, and mustard in combination showed that only coriander and cumin seed oils produced synergistic interactions, while others showed only additive effects [32]. This indicates that the proton-donating capability of coriander and cumin seed combinations was higher at low concentrations than other combinations. Similarly, the synergistic effect of oregano/thyme, cinnamon/thyme, mint/tea tree, and oregano/mint EOs in combination exhibited the highest antimicrobial activity because pathogens cannot develop resistance to multiple components of two or more EOs. Thus, the antioxidant and antibacterial potential can be increased by the synergistic interactions between different EOs or constituents of two or more extracts in combination.

It was revealed that the combination of different EOs produced synergism, resulting from the combined activities of several chemical constituents of EOs, and pathogens cannot easily develop resistance to multiple components of two or more EOs. Thus, synergistic interactions were observed between different EO combinations showing enhanced antioxidant and antibacterial activities with a reduction in the required doses of the combined agents.

The oregano EO (rich in thymol and carvacrol) was the most used EO combined with cinnamon, rosemary and thyme for many industrial applications. Similarly, thyme and clove EOs (rich in thymol and eugenol respectively) combined with cumin and cinnamon attributed synergism effects. The multicomponent nature and complexity of their structure in combination may work synergistically and improve the bioavailability of the combined agents, affecting multiple biochemical processes in the bacteria. The synergistic interaction of different EOs and their components as antioxidants and antimicrobial agents can prevent food spoilage caused by oxidation and microbial action, thereby increasing consumers' acceptance for packed food materials.

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Keywords

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