

Proceeding Paper

Essential Oils as Possible Candidates to Be Included in Active Packaging Systems and the Use of Biosensors to Monitor the Quality of Foodstuff [†]

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Abstract: Active packaging has gained interest in recent years. As well as protecting food from the environment, it can incorporate agents with specific properties to extend the shelf life of the food. As a requirement, it is essential that the active agent has a greater affinity for the food than for the packaging material and, in this sense, essential oils (EOs) are potential candidates to be included in this new packaging system. The use of EOs can add to food matrix antimicrobial and antioxidant properties, reduce the permeability of the packaging to water vapor and extend the shelf life of food products. However, their use has been limited because they can produce a strong flavor by interacting with other compounds present in the food matrix and modify the organoleptic characteristics. Although the nanoencapsulation of EOs can provide chemical stability and minimize the impact of the Eos on the organoleptic properties by decreasing their volatilization, some physical modifications have still been observed, such as plasticizing effects and color variations. In this sense, the quality of the food products and consumer safety can be increased by using sensors. This technology indicates when food products are degrading and informs us if specific packaging conditions have changed. This work focuses on highlighting the use of biosensors as a new methodology to detect undesirable changes in the food matrix in a short period of time and the use of nanotechnology to include EOs in active films of natural origin.

Keywords: active packaging; intelligent packaging; EOs; nanoencapsulation; biosensors

1. Introduction

There is a vast variety of foods that is sensitive to deterioration through the action of microorganisms and to the oxidation of lipids during storage. Packaging is used to protect foods against external and internal conditions, to ensure food safety and to avoid rapid deterioration caused by chemical and microbiological contamination. Furthermore, nowadays, consumers are more conscious about sustainability as a benefit of safe and healthy foods. As a result, the use of materials of natural origin (proteins, polysaccharides or lipids) as food packaging has gained attention in recent years. Simultaneously, two new technologies have emerged to protect foods and increase food shelf life, namely [1]: (i) intelligent packaging (IP) and (ii) active packaging (AP).

AP consists of the inclusion of chemical or bioactive compounds into the packaging system to ensure that the protective function of the packaging has a longer duration. This type of packaging interacts with the product, which can absorb or release components from the food [2,3]. Despite there being AP that contains different chemical additives, the use of bioactive compounds, such as essential oils (EOs), as new additives has gained attention. They are incorporated into films and coatings because of their important biological activities, such as their antioxidant and antimicrobial properties [4]. However, this technology presents some limitations to being applied at industrial level. For this reason, nanoencapsulation has emerged to improve food quality and reduce the limitations of AP in combination with active ingredients.

Regarding IP, its main objective is to control the conditions of packaged foods, such as the environment around them (i.e., storage conditions, food quality, sell by date, etc.). Biosensors are a type of sensor that belong to IP technology that have been widely employed at an industrial level in food processing during recent years. Specifically, electrochemical biosensors are the most used technology. However, they are still in the improvement phase of increasing their applications in packaging systems. These devices can detect undesirable changes or processes that can occur inside packaging systems, and transform them into a certain signal that can be easily analyzed [5,6].

This proceeding paper is focused on the use of EOs as possible natural additives or ingredients to be incorporated into the AP system, in the form of films or coatings, due to their antioxidant and microbial activities, and the use of biosensors as a possible tool to detect any undesirable changes inside of the packaging system. Finally, nanoencapsulation could be a suitable solution to improve food quality and safety even more.

2. Essential Oils in Active Packaging System

Active packaging (AP) is a novel method mainly utilized to prolong the shelf life of food products and to improve food quality and safety [3]. Many industries are interested in obtaining AP of natural origins that contains ingredients with bioactive compounds in order to avoid the use of chemical additives that can be harmful to human health, minimize the environmental impacts and ensure the acceptance of consumers. Essential oils (EOs) are one of the possible candidates for natural food additives.

EOs are volatile liquids of a lipid nature that can be obtained from plants. They are classified as GRAS (generally recognized as safe) food additives [7], thus their use has gained the attention of many researchers because of their antioxidant and antimicrobial activities. In addition, they can be used such as food preservatives or incorporated into edible films or coatings. Regarding food preservatives, their use is very limited due to their strong flavor and odor. As for edible films, there is a current trend in using materials such as polysaccharides, proteins or lipids as the edible films or coatings of packaging. EOs are used as additives or ingredients in edible emulsified films and coatings and can be incorporated into these edible matrices by several methods, emulsification being the most common. In fact, many studies are focused on using EOs as food additives in the packaging field to compete with the current packaging materials due to their substantial possibilities and adaptability [8–10].

2.1. Effect of the Incorporation of EOs in AP

The incorporation of EOs into the film matrix leads to a heterogeneous film structure featuring discontinuities, producing modifications to physical properties of the film such as tensile strength (TS), water vapor permeability (WVP), color, transparency and gloss [11]. Regarding TS, studies have shown different responses of TS when incorporating EOs into the film matrix [12–14]. In fact, the effect of the addition of EOs on the tensile properties of edible films depends on the specific interactions between the oil components and the polymer matrix. Concerning WVP, most studies have shown that the incorporation of EOs into the film matrix leads to an improvement of the water vapor barrier properties and a decrease in WVP [15,16]. Keeping this in mind, the hydrophobicity of EOs is a very

fluctuating characteristic because it depends on various factors. Finally, color, transparency and gloss are influenced by the type and concentration of EOs [11]. So, the incorporation of EOs into the matrix leads to specific physical modifications in the packaging that can reduce the quality and safety of the food products.

On the other hand, EOs are known for the presence of chemical compounds with antioxidant and microbial properties, which can be applied to avoid oxidation and increase food quality [11]. The antioxidant activity of the EOs occurs through different mechanisms: acting as O₂ scavengers; producing a barrier against O₂; and promoting a specific antioxidant action. In this sense, the incorporation of EOs can lead to the improvement of food quality and a reduction in food waste due to the oxidation [17]. However, their use is limited at an industrial level due to the possible migration of these compounds into the food product and, consequently, the modification of its organoleptic properties. Concerning microbial capacity, it depends on the characteristics of the EO and the type of microorganism. The antimicrobial action mainly inhibits the growth of food pathogens, thus ensuring protection against microbial deterioration [18]. Many industries are interested in obtaining packaging systems with antimicrobial properties, since they will promote a longer shelf life for food products and guarantee a better food quality. Table 1 shows some examples of AP where EOs with antimicrobial and antioxidant properties have been incorporated.

Table 1. Recent examples of active films containing EOs as the active agents, showing their main components and biological properties for packaged food products.

Film	EOs	Main Components of EOs	Biological Activity	Ref.
Gelatin	OLEO	Sabinene	Antimicrobial 2% OLEO (<i>B. subtilis</i> , <i>S. aureus</i> , <i>E. coli</i> , <i>P. aeruginosa</i> , <i>C. albicans</i>); Antioxidant DPPH 2% OLEO (52%)	[8]
Pectin	CEO	Cinnamaldehyde; L-linalool	Antimicrobial (<i>S. aureus</i> , <i>E. coli</i> , <i>L. monocytogenes</i>); Antioxidant: DPPH 1.5% CEO (64.73%)	[9]
Chitosan	PAEO	Caryophyllene; aromadendrene oxide; selinene	Antimicrobial (<i>S. aureus</i> , <i>S. typhimurium</i> , <i>K. pneumonia</i> , <i>P. aeruginosa</i> , <i>B. subtilis</i>)	[10]
Chitosan	ZEO	Thymol; γ -terpinene	Antioxidant DPPH (97.2%); Antimicrobial (<i>B. cereus</i> , <i>E. coli</i> , <i>P. aeruginosa</i> , <i>E. faecalis</i> , <i>S. aureus</i> , <i>A. flavus</i>)	[19]
Chitosan-GA	CEO	Cinnamaldehyde; L-linalool	Antioxidant: DPPH, maximum for 1:2 (Chitosan:GA)	[20]

Note: ZEO: *Zataria multiflora* essential oil; CEO: cinnamon essential oil; GA: gum arabic; OLEO: *Citrus sinensis* essential oil; OEO: oregano essential oil; PAEO: *Plectranthus amboinicus* essential oil; DPPH: 2,2-diphenyl-1-picrylhydrazyl.

2.2. Nanoencapsulation

Due to some disadvantages that EOs present when used as food additives (low solubility, high volatility, strong flavor, sensible to heat and light or the possibility of adversely affecting the organoleptic properties of food), many researchers began to focus their studies on the use of nanotechnologies in order to overcome these limitations and contribute to improving food preservation [21]. The nanoencapsulation technique consists of introducing an active agent (EO) into a polymer membrane with a diameter of 0.05–1 μm , known as a nanocapsule (Figure 1). This technique is used to protect the EOs against the previous limiting factors since this membrane acts as a barrier against the external environment, which prevents oxidation, masks unpleasant odors and taste and avoids

the loss of the volatile substances of the EOs. In addition, nanoencapsulation allows the controlled release of the EOs from the capsule, meaning that the release of the active agents occurs at the ideal place and time. Likewise, the nanoencapsulation of EOs can improve their biological activities, since their bioavailability depends on surface/volume ratio and particle size [22,23]. Keeping this in mind, the lower the particle size, the higher the surface/volume ratio or stability during the incorporation into the matrix. Many studies that employed this technique using EOs have shown excellent results in the quality and shelf life of food products [24,25].

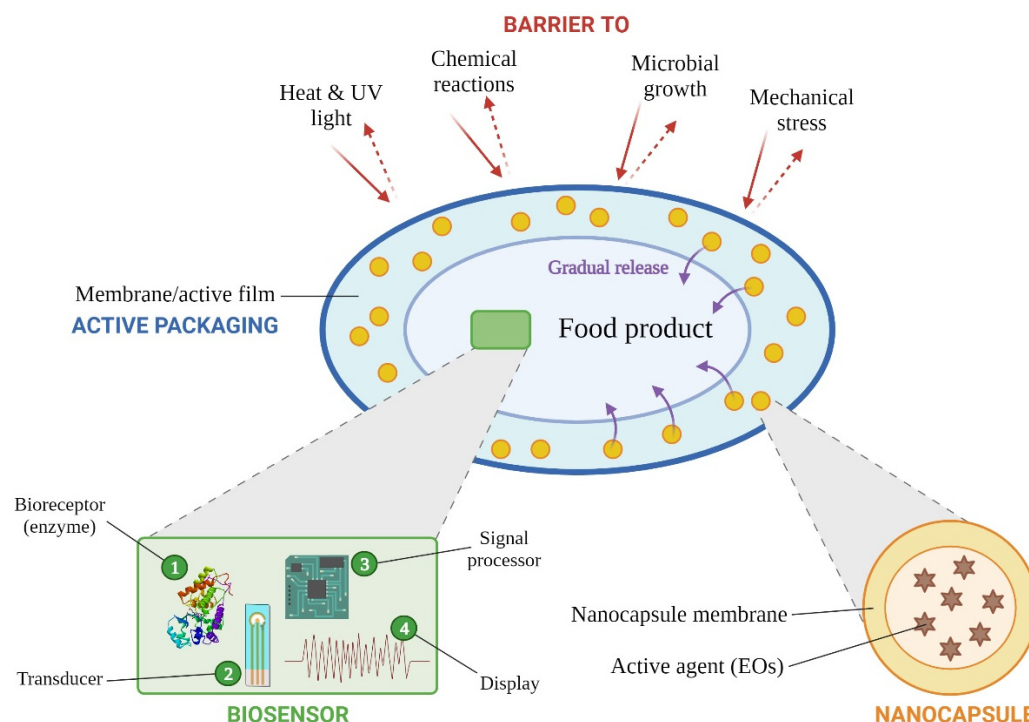


Figure 1. Biosensor structure, nanoencapsulation of EOs and functions of active films or coatings. Created with BioRender.com.

3. Biosensors

Besides AP, another technology has emerged in recent years, known as intelligent packaging (IP). IP is a packaging system that contains a certain device that provides information to the retailer or consumer about the state of the food product and its surrounding environment. In this sense, IP allows a constant communication about the state of the system with all steps of the supply chain, which is an important characteristic of this technology [3,26]. Keeping this in mind, this technology allows for the quick detection of unpleasant changes in the packaging system, an increase in food safety and the production of less food waste. Sensors, indicators and identification systems are the main components of IP, with sensors being the most common components and the ones that have received the most attention in recent years. All sensors contain: (i) a detection system, known as a receptor, which can detect specific analytes and transform its presence into an electric signal; (ii) a signal processor, known as a transducer, which is responsible for processing the generated signal; and (iii) an electronic system, which is responsible for displaying the measured properties. Depending on the type of analyte that they can detect, sensors can be chemical or biological, with the latter being the most promising technology to develop and improve IP systems. Biosensors are responsible for transforming biological responses into a processed signal, with enzymes, receptor proteins, antibodies and nucleic acids being the recognition elements (Figure 1) [5]. In fact, the use of enzymes as recognition elements is widely employed due to low production costs, lack of the need for additional instrumentation, small size and ease of use. Regarding the transducer group, biosensors

can be optical, mass-based, calorimetric or electrochemical, with the latter being the most used and the one that has gained the most attention. Electrochemical biosensors consist of devices that measure the electrochemical signal that is proportional to the analyte concentration [27]. However, their current applications in IP are limited to certain conditions since the biosensor structure can present biological components that have harmful effects. Furthermore, important improvements are needed in the biosensor structures in order to avoid the pretreatment of food samples and include degradation markers in packaging systems [28]. Therefore, more studies are required to improve and reduce these limitations.

4. Conclusions

In recent decades, both AP and IP have emerged as technologies that protect foods and increase food shelf life. In addition, due to a large percentage of consumers being conscious of environmental sustainability, many industries have employed natural food additives or ingredients, such as Eos, to replace synthetic chemical additives and the use of natural materials (i.e., proteins, polysaccharides or lipids) to reduce major waste. However, there are some limitations concerning the use of EOs as active agents, such as their low solubility, high volatility, strong taste and flavor, sensibility to heat and light, changes in organoleptic properties and modifications of the physical properties of the films or coatings. Nanotechnology, specifically the nanoencapsulation of EOs, has gained attention during recent years and has been presented as a new alternative to improve the quality of food products as many studies suggest that they have major benefits. On the other hand, biosensors, specifically electrochemical biosensors, could be the most promising technology for IP systems. In fact, the combination of AP with nanocapsules containing EOs and biosensors could lead to important improvements in food safety, an extension of products' shelf life and higher protection against oxidation and food deterioration mediated by the action of microorganisms.

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