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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. Despite 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 confer 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 provide 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 EOs on the organoleptic properties decreasing their volatilization, still some physical modifications have been observed such as plasticizing effects or color variations. In this sense, the quality of food products and consumer safety can be increased using sensors. This technology indicates when food products are degrading and gives information if some specific packaging conditions have changed. This work focuses on highlighting the use of biosensors as a new methodology to detect these 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.

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1. Introduction

There is a major variety of foods that is sensitive to deterioration by the action of microorganisms and to oxidation of lipids during storage. Packaging is used to protect foods against external and internal conditions, to ensure food safety and to avoid a rapid deterioration because of chemical and microbiological contamination. Furthermore, nowadays, consumers are more conscious about sustainability as the benefits 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 the protective function of packaging has a longer duration. This type of packaging interacts with the product, producing the absorption or the liberation of components from/to food [4,5]. Despite there are AP that contain different chemical additives, the use of bioactive compounds such as essential oils (EOs) as new additives has gained attention. Thus, they are incorporated into films and coatings because of their important biological activities such as antioxidant and antimicrobial properties [6]. However, this technology presents some limitations to be 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 sensors that belong to IP technology which have been widely employed at food industrial level during the last years. Specifically, electrochemical biosensors are the most used technology. However, they are still in the improving phase to increase their applications in packaging systems. These devices can detect the undesirable changes or processes that can occur inside packaging systems, and transform them into a certain signal that can be easily analyzed [2,3].

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

2. Essential oils in Active packaging system

Active packaging (AP) is a novel method mainly utilized to prolong food products shelf-life as to improve food quality and safety [5]. Many industries are interested in obtaining AP of natural origin that contain ingredients with bioactive compounds to avoid the use of chemical additives that can be harmful to human health, to minimize the environmental impacts and to ensure the acceptation of consumers. Essential oils (Eos) are one of those possible candidates as natural food additives.

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

2.1. Effect of the incorporation of EOs in AP

The incorporation of EOs in the film matrix leads to a heterogeneous film structure with discontinuity, producing modifications of the physical properties of the film such as tensile strength (TS), water vapor permeability (WVP), color, transparency and gloss [11]. Regarding TS, studies showed different responses of TS at 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 oil components and polymer matrix. Concerning WVP, most studies showed the incorporation of EOs into the film matrix led to an improvement of 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 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]. EOs antioxidant activity occurs through different mechanisms: acting as O_2 scavengers, producing a barrier against O_2. and promote a specific antioxidant action. In this sense, the incorporation of EOs can lead to improvement of food quality and reduction of food waste due to the oxidation [17]. However, their use is limited at industrial level due to the possible migration of these compounds to food product and consequently the modification of its organoleptic properties. Concerning microbial capacity, it depends on the EOs characteristics and the type of microorganism. The antimicrobial action is mainly directed to inhibit 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 duration of 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 active agents showing their main components and biological properties for packaged food product.

Film	EOs	Main components of EOs	Biological activity	Ref.
Gelatin	OLEO	Sabinene	Antimicrobial 2% OLEO (*B. subtilis, S. aureus, E. coli, P. aeruginosa, C. albicans*); Antioxidant DPPH 2% OLEO (52%)	[8]
Pectin	CEO	Cinnamaldehyde; L-linalool	Antimicrobial (*S. aureus, E. coli, L. monocytogenes*); Antioxidant: DPPH 1.5% CEO (64.73%)	[9]
Chitosan	PAEO	Caryophyllene; aromadendrene oxide; selinene	Antimicrobial (*S. aureus, S. typhimurium, K. pneumonia, P. aeruginosa, B. subtilis*)	[10]
Chitosan	ZEO	Thymol; γ-terpinene	Antioxidant DPPH (97.2%); Antimicrobial (*B. cereus, E. coli, P. aeruginosa, E. faecalis, S. aureus, A. flavus*)	[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, DPHH: 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 to overcome these limitations and contribute to improving food preservation [21]. Among others, nanoencapsulation technique consists of introducing an active agent (EOs) inside a polymer membrane with a diameter between 0.05-1 μm, known as nanocapsule (**Figure 1**). This technique is used to protect EOs against the previous limiting factors, since this membrane acts as a barrier against the external environment leading to the prevention of oxidation, masking unpleasant odors and taste, and avoiding the loss of volatile substances of EOs. In addition, nanoencapsulation allows controlled release of EOs from the capsule, allowing the release of these active agents takes place at the ideal place and time. Likewise, nanoencapsulation of EOs can improve their biological activities, since their bioavailability depends on surface/volume ratio and the particle size [22]. Keeping this in mind, the lower the particle size, the higher the surface/volume or stability during the incorporation into the matrix. Many studies that employed this technique using EOs showed excellent results of quality and shelf-life of food products.

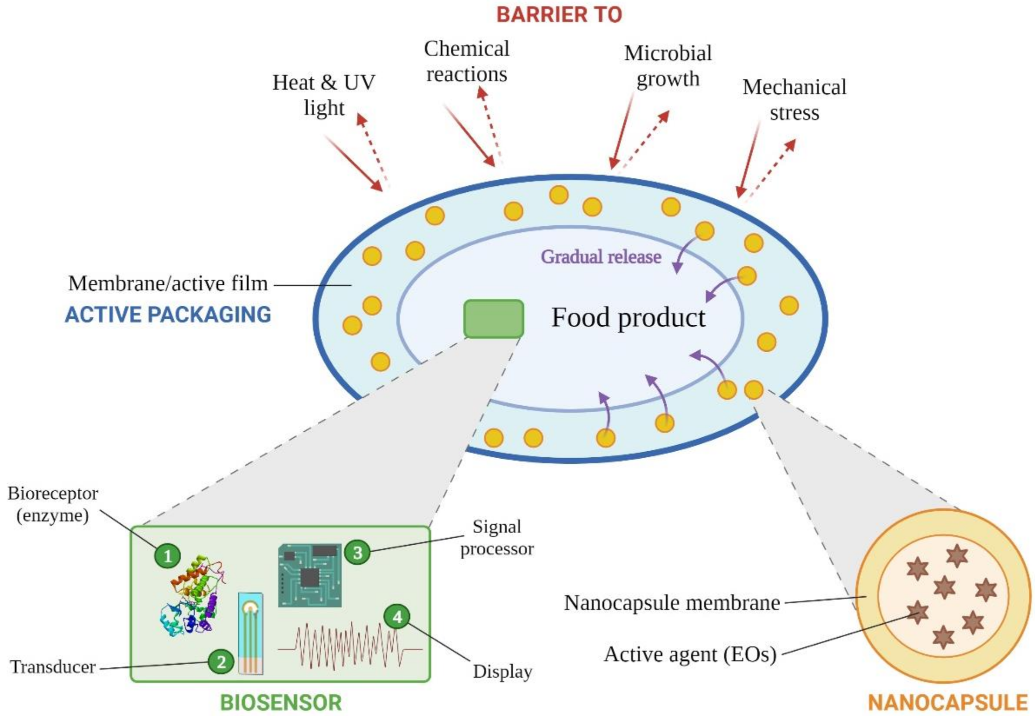

Figure 1. Biosensor structure, nanoencapsulation of EOs and functions of active films or coatings. Created with BioRender.com.

3. Biosensors

Besides AP, another technology has emerged in the recent years, known as intelligent packaging (IP). An important characteristic of IP is intellectual property since there is constant communication about the system state of interest to all steps of supply chains [5]. Keeping this in mind, this technology allows to quickly detection all those unpleasant changes in the packaging system, increasing food safety and producing less food waste. Sensors, indicators, and identification systems are the main components of IP, being sensors the most-used 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 processing, 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 they can detect, sensors can be chemical or biological, being the latter the most promising technology to develop and improve IP systems. Biosensors are responsible for transforming biological responses in a processed signal, being enzymes, receptor proteins, antibodies and nucleic acids the recognition elements (**Figure 1**) [2]. In fact, the use of enzymes as recognition elements is widely employed because of their low production costs, no need for additional instrumentation, short size and easy use. Regarding transducer class, biosensors can be optical, mass-based, calorimetric, and electrochemical, 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 [23]. However, their current applications in IP are limited to certain conditions since the biosensor structure can present biological components with harmful effects. Furthermore, important improvements are needed on the biosensor structures to avoid the pretreatment of food samples and to include degradation markers in packaging systems [24]. Therefore, more studies are required to improve and reduce these limitations.

4. Conclusion

In recent decades, both AP and IP have emerged as technologies to protect foods and increase food shelf-life. In addition, due to a major percentage of consumers that are conscious about environmental sustainability, many industries have employed natural origin food additives or ingredients such as EOs to replace synthetic chemical additives and the use of natural origin materials (*i.e.,* proteins, polysaccharides or lipids) to reduce major wastes. 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 or modifications in the physical properties of the films or coatings. Nanotechnology, specifically nanoencapsulation of EOs, has gained attention during these last years and is presented as a new alternative to improve the quality of food products since many studies suggest their major benefits. On the other hand, biosensors, specifically electrochemical biosensors, could be the most promised 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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