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Applications of active packaging for increasing microbial stability in foods: natural volatile antimicrobial compounds

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Given that foods are dynamic systems, the improvement of classic packaging technologies (i.e., vacuum, modified atmospheres) or the development of new ones constitutes a continuous challenge for the food industry. The last decade, among the most promising packaging technologies that have received a lot of attention by the scientific community is the antimicrobial active packaging (AAP), focusing especially on the application of natural antimicrobial compounds through carriers. Among them, the volatile substances, such as essential oils, plant extracts, or ethanol are of great interest due to their ability to be easily released in the headspace of the packaging, increasing food microbial stability while mildly affecting the sensory attributes. In this context, the present article shares insights related to the current regulatory status and literature approaches of AAP using natural volatile antimicrobial compounds through various carriers in order to motivate the food industry to adopt such an innovative technology.

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Introduction

Active packaging is accurately defined as 'packaging in which subsidiary constituents have been deliberately included in or on either the packaging material or the package headspace to enhance the performance of the package system' [1]. Principal active packaging systems include O_2 scavengers, moisture absorbers, and CO_2 emitters; however the version of antimicrobial active packaging (AAP) is of great scientific and commercial interest. In simple terms, the AAP interacts with the packaged food or the package headspace in order to reduce, retard or even inhibit the growth of spoilage and pathogenic microorganisms [2].

The main examined concepts of AAP are based on how the antimicrobial compound is being applied:

- Concept No 1: Addition of the antimicrobial compound (mainly volatiles) into separate carriers (i.e., sachets, pounces, or pads) inside the package having no contact with the food → The mode of action is based on evaporation in the headspace of the packaging. With regard to the application of the carrier, they are usually attached on the inner side of the package or placed in a separate section (e.g., compartmentalized package), ensuring the absence of contact with the food. This concept has been successfully studied on products of meat and plant origin (Tables 1 and 2).
- Concept No 2: Incorporation of the antimicrobial compound (volatiles and/or non-volatiles) into carriers (edible or not) having indirect contact (a part of the antimicrobial compound is immobilized to the carrier) with the food → The mode of action is mainly based on diffusion, however if volatile antimicrobial compounds are used a part of antimicrobial action is related to the released vapours in the headspace of the packaging. Edible carriers, that is, coatings and films are characterized as an extensively interacting grid that possesses a three-dimensional gel-type structure, produced by polymers of natural origin, that is, polysaccharides, proteins, or lipids. To differentiate films from coatings, films are defined as a dried, thin layer of biopolymer separately added (i.e., wrap or separation layer between product slices) on food, while coatings involve the formation of films directly on the food surface [3]. They have received remarkable attention, nowadays, as potential alternatives to conventional synthetic packaging materials (i.e., plastic), since they are environmentally friendly and cost-effective [4•]. Another way to immobilize an antimicrobial compound is via encapsulation into edible biopolymer matrices (i.e., alginates) in the form of beads. In contrast to coatings and films, beads could be applied both on liquid and solid foods [5]. Tables 1 and 2 show a significant number of studies, which have investigated this concept on meat and fish products, fruits, vegetables, and cheeses. An exception of this concept is the addition of antimicrobial compound in synthetic absorbent pads commonly placed under the food. By this way the pad could have double use: carry and release volatile antimicrobial compounds providing in parallel the convenience of an absorbent material (i.e., absorbing the exuded liquid from meat products) inside the packaging.

Table 1

Applications of AAP by using essential oils, plant extracts, or their active compounds through carriers in order to extend the shelf-life or improve the safety of different food products.

Carrier		Antimicrobial compound (concentration)	Food product	Target microorganism	Indicative antimicrobial effect	Reference
Coatings	Na-Alginate	Lemongrass EO (0.1%, 0.3%, and 0.5% (w/w))	Fresh-cut pineapple	TVC Yeasts and moulds	Microorganisms were significantly inhibited on coated samples (0.3% and 0.5% (w/w)) compared to controls after 16 days at 10 °C.	[33]
	Chitosan Gum Arabic Aloe vera	Thyme EO (1% (v/v))	Avocadoes	*Colletotrichum gloeosporioides* (anthracnose)	Significant reduction of the incidence and severity of anthracnose after 5 days at 20 °C.	[34]
	Whey protein isolate	Oregano or clove EO (10 and 20 g/kg)	Chicken breast fillets	Total mesophilic bacteria Psycrotrophic bacteria Enterobacteriaceae *Pseudomonas* spp. LAB	The shelf-life of chicken fillets was doubled (from 6 to 13 days) when coatings of 20 g/kg oregano EO was applied during storage at 4 °C.	[35]
	Composite of κ-Carrageenan/ chitosan	AITC (10, 25, 50, and 100 μL/g)	Chicken breasts	*Campylobacter jejuni* LAB Total aerobic bacteria	Coatings containing: • 50 or 100 μL/g AITC reduced *C. jejuni* to undetectable levels after 5 days at 4 °C. • ≥25 μL/g AITC reduced total aerobic bacteria and LAB by 1.1 log CFU/g and 2.5 log CFU/g, respectively, after 21 days at 4 °C.	[36]
	Chitosan	Carvacrol, cinnamaldehyde, or trans-cinnamaldehyde (0.1%, 0.2%, and 0.5%)	Blueberries	TVC Yeasts and moulds	Reduction of TVC and yeasts/moulds during storage at 5, 10, and 20 °C, regardless of antimicrobials' type and concentration.	[37]
	Pullulan	Sweet basil extract (24 mg/cm^2)	Apples	*Rhizopus arrhizus* Total mesophilic bacteria	Low antibacterial activity against total mesophilic bacteria and good antifungal protection against *R. arrhizus* on apples.	[38]
	Chitosan	Lemongrass EO (0.5% and 1.0% (v/v))	Bell peppers	*Colletotrichum capsici*	Improved control of anthracnose disease incidence with the percentage of diseased fruits being 33.3% and 26.7%, for 0.5% (v/v) EO and 1% (v/v) EO treatments, respectively, after 21 days at room temperature.	[39]
	Chitosan	Carvacrol (0.125% and 0.25% (v/v))	Tilapia fillets	TVC Total coliforms *Vibrio* spp.	TVC, total coliforms, and *Vibrio* spp. were reduced by 2.4–3.5, 1.0, and 0.7–2.8 log CFU/g, respectively, after storage for 21 days in ice.	[40]
	Na-Alginate	Eugenol (0.1% and 0.2% (w/w)) and/or citral (0.15% and 0.3% (w/w))	Arbutus unedo fresh fruit (strawberry tree)	TVC Yeasts and moulds	Eugenol treatments (0.1% and 0.2% (w/w)) followed by the combination of Citral 0.15% + Eugenol 0.1% were the most efficient in controlling spoilage after 28 days at 0.5 °C.	[41]
	Starch	Extract of herb *Adiantum capillus-veneris* L. (0.1%, 0.2% and 0.3% (v/v))	Fresh-cut pears	TVC Yeast and moulds Total coliforms	Fresh-cut pears were positively affected by the coating treatment decreasing bacterial and fungal contamination during storage at 4 °C for up to 10 days.	[42]
	Whey protein isolate	Thyme or clove EO (1.5% (v/v))	Kashar cheese	*E. coli* O157:H7 *Staphylococcus aureus* *L. monocytogenes*	All tested pathogens were decreased in samples coated with thyme and clove films.	[43]
	Na-Alginate	Thyme EO (0.5% (w/w))	Chicken breast fillets	TVC	Shelf-life was increased by 1.75 days compared to controls at 4 °C.	[44]
	Na-Alginate	Lemongrass EO (0.1%, 0.5% and 1% (v/v))	Fresh-cut Fuji apples	*E. coli* Psychrophilic bacteria Yeasts and moulds	*E. coli* population remained undetected and natural microflora was completely inhibited during 2 weeks of refrigerated storage of samples coated with solutions containing 0.5% or 1% (v/v) EO.	[45]
	Composite of fish gelatin and chitosan	Garlic and lime juice extract (30% (v/v))	Salmon fillets	TVC Psychrophilic bacteria	Fillets coated with garlic incorporated to gelatin–chitosan coating had stronger antimicrobial action compared to lime after 16 days at 6 °C.	[46]
	Zein	Cinnamon or mustard EOs (5%, 10%, 15%, and 20% (v/v))	Cherry tomatoes	*S. enterica* serovar Typhimurium	Zein with 20% (v/v) cinnamon or mustard EOs caused a >5.0 log CFU/g reduction of *S.* Typhimurium compared with initial control tomato samples.	[47]