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New era of smart packages in food industry: A review

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Abstract
In many food products, microbial growth occurs primarily at the surface. More recently, the concept of incorporating antimicrobial agents directly into package films that contact the surface of the food has been developed. Active packaging systems based on the application of packaging materials with incorporated antimicrobial agents provide one of promising trends in food processing. Antimicrobial food packaging reduces, inhibits or retards the growth of pathogenic and/or spoilage microorganisms that may be present on packaged food surfaces due to releasing of antimicrobial components. These systems can contribute to the shelf-life extension, the quality maintenance and the storage stability improvement of packaged foodstuffs. Research and development of antimicrobial materials for food applications such as packaging and other food contact surfaces is expected to grow in the next decade with the advent of new polymer materials and antimicrobials.

Keywords: Microbial growth, antimicrobial agents, active packaging and shelf life

Introduction
The principal function of packaging is protection and preservation from external contamination (Robertson, 2006) [5]. This function involves retardation of deterioration, extension of shelf life and maintenance of quality and safety of packaged food. Packaging protects food from environmental influences such as heat, light, the presence or absence of moisture, oxygen, pressure, enzymes, odours, microorganisms, insects, dirt and dust particles, gaseous emissions, and so on. All of these cause deterioration of foods and beverages (Marsh and Bugusu, 2007) [4] Prolonging shelf life involves retardation of enzymatic, microbial and biochemical reactions through various strategies such as temperature control; moisture control; addition of chemicals such as salt, sugar, carbon dioxide or natural acids; removal of oxygen; or a combination of these with effective packaging. Precise integration of the product, process, package and distribution is critical to avoid recontamination. The ideal packaging material should be inert and resistant to hazards and should not allow molecular transfer from or to packaging materials (Robertson, 2006) [5].

Active packaging, sometimes referred to as interactive or “smart” packaging, is intended to sense internal or external environmental change and to respond by changing its own properties or attributes and hence the internal package environment. The goal of active packaging, in conjunction with other food processing and packaging, is to enhance preservation of contained food and beverage products.

“Antimicrobial packaging” is one of many applications of active packaging (Floros *et al*., 2000) [1]. Antimicrobial packaging is the packaging system that is able to kill or inhibit spoilage and pathogenic microorganisms that are contaminating foods. The new antimicrobial function can be achieved by adding antimicrobial agents in the packaging system and/or using antimicrobial polymers that satisfy conventional packaging requirements. When the packaging system acquires antimicrobial activity, the packaging system (or material) limits or prevents microbial growth by extending the lag period and reducing the growth rate or decreases live counts of microorganisms (Han, 2000) [2].

Therefore, the primary goals of an antimicrobial packaging system are, (i) safety assurance, (ii) quality maintenance, and (iii) shelf-life extension, which are the reversed order of the primary goals of conventional packaging systems. Now a day’s food security is a big issue and antimicrobial packaging could play a role in food security assurance.

What are antimicrobials?

Microbes that contaminate packaging materials typically are controlled by using heat, steam, or radiation or by the addition of antimicrobial additives. "Packaging antimicrobials" are materials that can be added to packaging materials and will prevent microbial growth. Use of antimicrobial packaging offers a degree of protection and extends the shelf life of perishable food products.

Table 1: Antimicrobial agents used in Food Packaging.

Class	Examples
Organic Acids	Propionic, Benzoic, Sorbic
Bacteriocins	Nisin
Spice Extracts	Thymol, *P*-Cymene
Thiosulfinates	Allicin
Enzymes	Peroxidase, Lysozyme
Proteins	Conalbumin
Isothiocyanates	Allylisothiocyanate
Antibiotics	Imazalil
Fungicides	Benomyl
Chelating Agents	EDTA
Metals	Silver
Parabens	Heptylp

***Source*:** Hotchkiss, 1997 [3].

Types of antimicrobial packaging

Antimicrobial packaging can take several forms including:

1. Addition of sachets/pads containing volatile antimicrobial agents into packages.
2. Incorporation of volatile and non-volatile antimicrobial agents directly into polymers.
3. Coating or adsorbing antimicrobials onto polymer surfaces.
4. Immobilization of antimicrobials to polymers by ion or covalent linkages.
5. Use of polymers that are inherently antimicrobial.
6. Bacteriocins
7. Antimicrobial enzymes
8. Radiation-Emitting Film
9. Antimicrobial activity of silver and copper ions

1. Addition of sachets/pads containing antimicrobial agents into packages

The most successful commercial application of antimicrobial packaging has been sachets that are enclosed loose or attached to the interior of a package. Three forms have predominated: oxygen absorbers, moisture absorbers and ethanol vapor generators. Oxygen and moisture absorbers are used primarily in bakery, pasta, produce and meat packaging to prevent oxidation and water condensation. Although oxygen absorbers may not be intended to be antimicrobial, a reduction in oxygen inhibits the growth of aerobes, particularly molds. Moisture absorbers can reduce water activity (aw), also indirectly affecting microbial growth.

2. Incorporation of antimicrobial agents directly into polymers

Incorporation of bioactive agents including antimicrobials into polymers has been commercially applied in drug and pesticide delivery, household goods, textiles, surgical implants and other biomedical devices. The number of recently published articles and patents suggest that research on the incorporation of antimicrobials into packaging for food applications has more than doubled in the past 5 years. Of all the antimicrobials, silver substituted zeolites are the most widely used as polymer additives for food applications, especially in Japan. Sodium ions present in zeolites are substituted by silver ions, which are antimicrobial against a wide range of bacteria and molds. Commercial examples of silver substituted zeolites include Zeomic, Apacider, AgIon, Bactekiller and Novaron.

3. Coating or adsorbing antimicrobials to polymer surfaces

Early developments in antimicrobial packaging incorporated fungicides into waxes to coat fruits and vegetables and shrink films coated with quaternary ammonium salts to wrap potatoes (Shetty and Dwelle, 1990) [6]. Other early developments included coating wax paper and cellulose casings with sorbic acid for wrapping sausages and cheeses. Antimicrobials that cannot tolerate the temperatures used in polymer processing are often coated onto the material after forming or are added to cast films.

4. Immobilization of antimicrobials by ionic or covalent linkages to polymers

This type of immobilization requires the presence of functional groups on both the antimicrobial and the polymer. Examples of antimicrobials with functional groups are peptides, enzymes, polyamines and organic acids. In addition to functional antimicrobials and polymer supports, immobilization may require the use of 'spacer' molecules that link the polymer surface to the bioactive agent. These spacers allow sufficient freedom of motion so the active portion of the agent can contact microorganisms on the food surface. Spacers that could potentially be used for antimicrobial packaging include dextrans, polyethylene glycol, ethylenediamine and polyethyleneimine, due their low toxicity and common use in foods.

5. Use of polymers that are inherently antimicrobial

Some polymers are inherently antimicrobial and have been used in films and coatings. Cationic polymers such as chitosan and poly-L-lysine promote cell adhesion. Chitosan has been used as a coating and appears to protect fresh vegetables and fruits from fungal degradation. Although the antimicrobial effect is attributed to antifungal properties of chitosan, the chitosan acts as a barrier between nutrients contained in produce and microbes.

6. Bacteriocins

A group of antimicrobial substances known as bacteriocins - proteins derived from microorganisms, are effective against microorganisms such as *Clostridium botulinum*. One such compound, nisin, has been accepted by regulatory authorities in some countries, for food use. These peptide type compounds can theoretically be attached to the surface of food-contact films. It has not been reported whether such bound bacteriocins would be effective.

7. Antimicrobial enzymes

Antimicrobial enzymes might also be bound to the inner surface of food contact films to produce microbial toxins. Several such enzymes exist, such as glucose oxidase, which forms hydrogen peroxide - a potent antimicrobial.

8. Radiation-Emitting Film

A third possibility for antimicrobial films is to incorporate radiation - emitting materials into food-packaging films. Japanese researchers have reportedly developed materials that emit long-wavelength infrared (IR) radiation on exposure to water or water vapor. This finding is reported in Japanese publications to be effective against microorganisms without the risks associated with higher energy radiation.

9. Antimicrobial activity of silver and copper ions

The antimicrobial agents with the greatest potential appear to be those containing releasable silver salts. Antimicrobial activity of metals is due to the minute quantity of ions formed from the metals. Copper ions can destroy microorganisms and viruses, and copper is indispensable for life as a constituent of metallic enzymes. Recently, water filters and daily utensils utilizing antimicrobial activity of copper ion have been commercially available. Copper is regarded as toxic in contact with food, and generally it is no longer permitted as an additive by regulatory authorities.

Active packaging

Active packaging is an innovative approach to maintain or prolong the shelf-life of food products while ensuring their quality, safety, and integrity. As defined in the European regulation (EC) No 450/2009, active packaging comprises packaging systems that interact with the food in such a way as to "*deliberately incorporate components that would release or absorb substances into or from the packaged food or the environment surrounding the food*" (European Commission 2009). Active packaging systems can be divided into active scavenging systems (absorbers) and active-releasing systems (emitters). Whereas the former remove undesired compounds from the food or its environment, for example, moisture, carbon dioxide, oxygen, ethylene, or odor, the latter add compounds to the packaged food or into the headspace, such as antimicrobial compounds, carbon dioxide, antioxidants, flavors, ethylene, or ethanol. Table 1 provides an overview of the primary active packaging technologies and their potential benefits in food applications. [Marsh K. and Bugusu B. (2007).] [4].

Table 2: Potential active packaging for food applications

Type of active packaging	Type of food	Potential benefit
Active scavenging systems (absorber)		
Oxygen scavenger	(Sliced) cooked meat products	Prevention of discolouration
	Grated cheese, (par-baked) bakery products	Prevention of mold growth
	Fruit and vegetable juices	Retention of vitamin C content, prevention of browning
	Seeds, nuts, and oils; fat-containing instant powders, fried snacks; dried meat products	Prevention of rancidity
Moisture scavenger	Mushrooms, tomatoes, strawberries, maize, grains, seeds, fresh fish, and meat	Extension of shelf life through maintaining moisture content, decrease in moisture condensation in the packaging, positive impact on the appearance, reduction in browning or discoloration
Ethylene absorber	Climacteric fruits and vegetables	Reduction in ripening and senescence, thereby enhancing quality and prolonging shelf-life
Active releasing systems (emitter)		
Antioxidant releaser	Fresh fatty fish and meat; fat-containing instant powders; seeds, nuts, and oils; fried products	Improvement of oxidative stability
Carbon dioxide emitter	Fresh fish and meat	Extension of microbiological shelf life, reduction in head space volume of modified atmosphere packaging
Antimicrobial packaging systems	Fresh and processed meat, fresh and smoked fish, fresh seafood, dairy products, fresh and processed fruits and vegetables, grain, cereals and bakery products, ready-to-eat meals	Inhibition or retardation of bacterial growth, extension of the shelf-life

Intelligent food packaging

Intelligent food packaging is becoming more popular because of the growing usage of active packaging, that requires monitoring the performance of active components and the overall packaging conditions, and because of intelligent systems enabling reliable and rapid product differentiation, traceability, and other interactive features. In this chapter three main intelligent packaging (IP) systems are presented: two-dimensional barcodes and radiofrequency identification systems, intended mainly for storage, distribution, and traceability purposes; indicators, which provide immediate qualitative information about measured quantity in the food environment; sensors for quantification of the analytes to evaluate the food quality and the package integrity. The aim is to provide an overview of currently available commercial applications of IP systems and latest research trends and innovations. Intelligent packaging is an emerging and existing area of food technology that can provide better food preservation and extra convenience benefits for consumers. The introduction of quality and freshness indicators (temperature indicators, time-temperature integrators, and gas-level controls), the increased convenience of product manufacturing and distribution methods, the smart permeability films, and the theft and counterfeiting evidence systems maximize the safety and quality of food products. Thus, intelligent packaging systems will improve the product quality, enhance the safety and security of foods, and consequently decrease the number of retailer and consumer complaints. The global market for smart packaging is expected to reach $26.7bn by 2024. Smart packaging refers to packaging systems with embedded sensor technology used with foods, pharmaceuticals, and many other types of products. It is used to extend shelf life, monitor freshness, display information on quality, and improve product and customer safety. In addition, smart packaging offers new business opportunities based on digitization and thus fits into the broader realm of Industry 4.0. In this paper, the authors provide an introductory overview of smart packaging and discuss its underlying base technologies. [Robertson G. (2006)] [5].

Conclusion
Antimicrobial packaging is a promising form of active food packaging in which the antimicrobial substances incorporated into package materials can control microbial contamination by reducing the growth of the microorganisms. Antimicrobial packaging systems can inhibit the growth of spoilage and pathogenic microorganisms, and contribute to the improvement of food safety and the extension of shelf-life of the packaged food. Research and development of antimicrobial materials for food applications such as packaging and other food contact surfaces is expected to grow in the next decade with the advent of new polymer materials and antimicrobials.

Future research
Antimicrobial packaging is gaining interest from researchers and industry due to its potential to provide quality and safety benefits. Currently, development is limited due to availability of antimicrobials and new polymer materials, regulatory concerns and appropriate testing methods. New coating binder materials compatible with polymers and antimicrobials, functionalized surfaces for ionic and covalent links and new printing methods combined with encapsulation are examples of the technologies that will play a role in the development of antimicrobial packaging.

Future work will focus on the use of biologically active derived antimicrobial compounds bound to polymers. The need for new antimicrobials with wide spectrum of activity and low toxicity will increase. It is possible that research and development of ‘intelligent’ or ‘smart’ antimicrobial packages will follow. These will be materials that sense the presence of microorganism in the food, triggering antimicrobial mechanisms as a response, in a controlled manner. Antimicrobial packaging can play an important role in reducing the risk of pathogen contamination, as well as extending the shelf-life of foods.

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