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Antimicrobial Packaging and Its Use in Food Industry: A Review

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ABSTRACT
The interest for the development of new active packaging material has increased rapidly in last few decades. The present review makes an attempt to current a viewpoint on the research trends and solution in the sphere of Antimicrobial packaging materials. Antimicrobial active packaging is an alternative to protect perishable products during their storage, production and distribution, as this packaging material has antibacterial, antifungal, and antioxidants activities which can be induced by the main material or polymer used for packaging. Also, they can be induced by the addition of various natural agents to synthetic agents, both organic and inorganic. With the use of antimicrobial packaging, food industry tries to change the public perception and focus on the antimicrobial packaging solution which will share the shelf life and provide healthier foods, thus vanishing the waste of agriculture resources, but will also be reduced the plastic pollution. This review underlines the most recent trends in the use of new edible coatings enriched with antimicrobial agents, edible or not, using as support traditional and new polymer with focus on natural compounds.
Key Words: Antimicrobial, Packaging, Thymol, Active packaging, bacteriocin, processed food.

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INTRODUCTION

Statistical data of the Food and Agriculture Organization of the United Nations, FAO, shows that one third of the produced food gets wasted or lost each year due to expiry of shelf life, alteration, spoilage in the food by microbial activity [1]. Food safety and quality has been compromised as a result of need and increase demand of minimally processed food [2]. On the other hand, the search for more natural foods which is healthy, minimally processed and re ready to eat products has resulted in an increase in requirement of safe and high-quality food products [3]. These new social trends or requirements with changes in the former procedure to make food processing faster and efficient and have a higher interest to obtain food products with a better and longer shelf life [4]. According to FAO "About 40-50% fruits and vegetables, 35% of fish, 30% of cereals and 20% of dairy products are lost yearly. The main reason for their wastage is in the presence of bacteria, fungi and oxygen-driving processes and presence of some enzymes"[5]. To reduce this wastage packaging is however one of the possible ways to provide an increased margin of safety and quality. Hence, Antimicrobial packaging is a next generation packaging with microbial inhibiting as well as conventional barrier properties [6].

Perishable food products can be subjected to degradation by many different environmental effects, including contamination by microorganisms. Therefore to increase shelf life and quality, processed foods require protection from spoilage during storage, preparation and distribution. Also, to maintain odour, flavour, colour and textural properties of the fresh food protection from microorganisms has to be maintained [7].

At present, almost each food packaging material is based on a petrochemical polymer because of historic factors like: low cost and good barrier performances. These polymers are non-biodegradable and have already raised a lot of environmental concerns [8-10]. Also, traditional preservation techniques, such as heat treatment, salting or acidification are being used for a long time by the food industry to prevent the growth spoilage and pathogenic microorganism in food products, but eventually they results in loss of nutritional value [11]. However, new plans related to preservation techniques have been proven to be more effecting in protecting food. This is particularly the case for antimicrobial films [4].

Antimicrobial packaging technology would have played an important role in extending shelf life of food products also it has reduced the risk from pathogens [12]. These packaging have attracted the researcher of the food industry as they can improve the safety, quality, and functionality of food products [4].

Antimicrobial packaging has many applications and attractive innovation of active packaging system and/or using actively functional polymers [14]. The Antimicrobial packaging system is prepared either by adding sachets with volatile antimicrobial agents inside the package to incorporate the active agent directly into biopolymers and form coating or grafting the antimicrobial substances on polymeric surface to the use of intrinsic microbial pads or polymers [16-18]. The primary goals of an antimicrobial packaging are:

1. Safety assurances
2. Quality management
3. Shelf life extension,

Which is the reverse order of primary goals of conventional packaging system [19].

All antimicrobial agents have different activities on microorganisms due to the various characteristics and physiologies of microorganisms. Besides the microbial characteristics the function of antimicrobial agents is to understand the efficacy as well as the limit of the activity. Some of these agents inhibit the essential metabolic pathways of microorganism while some others alter cell membrane/ wall structure. The basic principle of antimicrobial packaging is based on hurdle technology. It allows the use of hurdles like water activity, pH, redox potential, heat treatment, etc. to get a maximum lethality of microorganism at an optimum level by a combination of two or more such hurdles so that minimum damage to the nutritional and sensory properties of food can occur [20]. Intelligent use of these hurdles in food production ensures that the final product have an adequate shelf life and remain safe [21]. This packaging system have another hurdle to prevent the degradation of total quality of packaged food while satisfying the conventional function of moisture and oxygen barriers as well as physical protection. In Antimicrobial polymeric material , release and absorption and immobilization are three types of modes for antimicrobial function [22]. However, Release type allows the migration of antimicrobial agents into food inside packages and inhibits the growth of microbes. Absorption mode of antimicrobial system removes essential factors of microbial growth from the food system and inhibits the growth of microorganism. Immobilization doesn't release antimicrobial agents but suppress the growth of microorganisms at the contact surface such as immobilized lysozyme and glucose oxidase enzyme on polymer packages [19].

There are two types of antimicrobial packaging system:

1. Package/ food system
2. Package/headspace/food system

In package/food system diffusion involves the main migration phenomena between the packaging material and the food and partitioning at the interface [20].

In package/headspace/food system, the evaporation of a substance to the headspace is the main migration phenomena. Hence, a volatile active substance should be used. Then the active substances which are equilibrated may diffuse into the food [20].

COMPOSITION OF ANTIMICROBIAL PACKAGING

Antimicrobial packaging by material

It is divided into two groups:

1. Biodegradable packaging
2. No biodegradable packaging

Biodegradable packaging is, in which the degradation process results in lower molecular weight fragments produced by action of natural occurring microorganism [21]. By adding antimicrobial properties to the biodegradable packages can enhance protection against food spoilage, extending the shelf life. By providing an alternative material to plastic, the scientists have put focus on biopolymers [22]. This packaging includes edible coating and films from protein, lipid and starch, chitosan polyactic acid, polyhydroxy butyrate and polyhydroxy alkanoate [21].

These edible films represent a protection packaging with Antimicrobial activity for the food safety. These edible packaging material or coating must be non toxic, adherent to food surface, be tasteless or present an agreeable taste, have good barrier properties and prevent water depletion of food, must have a good stability in time and prevent the mould formation, good appearance in order to be accepted by consumer and must be economically viable [23].

Polysaccharide based films or Chitosan, one of the most abundant polymer is a boom for such innovative edible microbial packaging. It's a polysaccharide, with intrinsic antibacterial activity. It can protect the food by multiple mechanisms. It can block the microorganisms access to the food as a physical barrier. It can block the oxygen transfer inhibiting respiratory activity of microorganisms [24].

Starch is another common polysaccharide which is being used for edible films. Simple starch films mixed with various natural compounds can form efficient antimicrobial packaging materials [25].

Non-biodegradable packaging does not undergo degradation into fragments by microorganisms such as polymeric packaging material from nylon, low density polyethylene (LDPE). High density polyethylene (HDPE) and polystyrene, etc. Most of the synthetic polymers are non-biodegradable and are superior for usage as food packaging, with advantage of low cost density, inert, excellent barrier properties, good mechanical strength, high transparency, ability to be heat-sealed and easily printable [21].

Antimicrobial Agents

A wide variety of antimicrobial agents have been described for their use in coating formulation for packaging food [20]. The essential requirement for the formulation of system of antimicrobial packaging is food grade condition [27]. Antimicrobial agents, can be classified into three groups:- chemical agents, natural agents and probiotics [19]. Agents derived from natural sources have been traditionally used as food additives and been awarded with Generally Recognised as Safe(GRAS) [7]. Organic acids and their salts, sulphites, nitrites, antibiotics and alcohol are the most used chemical as synthetic antimicrobial agent due to their well known effectiveness and low-cost. Also many of them are also labelled with the GRAS status [20, 28]. Numerous inorganic compounds have antimicrobial activity with embedded in packaging system. Silver and porous materials complexes with silver such as Zeolite, used as antimicrobial particles besides polymeric films or surface coating [29]. Zinc particles shows strong antimicrobial activity against microorganisms by affecting cell wall permeability, respiration and cellular respiration [30].

The antimicrobial activity of different spices and herbs has been known from ancient times. Numerous studies have reported the preservation abilities of plant derived compounds in food production. Among them essential oils and their main compartment such as thymol, carvacrol,p-cymene and *y*- terpiene in thymus are gaining popularity [31, 32].

Natural antimicrobials from animal origin like Chitosan has gained attention of scientists. Chitosan offers the possibility of obtaining coating to cover fresh or processed foods to extend their shelf life [33].

Other antimicrobials obtained from bacteria, such as Nisin, Pediocin Natamycin or Reuterin have also been used against target microorganisms [34].

TYPES OF ANTIMICROBIAL PACKAGING

Antimicrobial packaging exists in various forms such as sachets / pads having volatile antimicrobial agents, polymers in which volatile and non-volatile antimicrobial agents are directly incorporated [6].

- **Addition of sachets or pads containing antimicrobial agents to packages**
  Sachets are enclosed or loose attached to the inner side of a package they are basically oxygen absorbers, oxygen absorbers and vapour of ethanol generator's [6]. Sachets containing Ethanol vapour generating system are used in bakery and fish dried processed products to inhibit growth of moulds [35].
- **Inherent antimicrobial polymers**
  Coatings of Chitosan inherently possess antimicrobial properties Chitosan coating applied to fruits and vegetables protect them from fungal degradation and act as a barrier between microorganism and nutrient [36]. These films and coatings also act as a carrier of various antimicrobial agents such as organic acids and spices [37].
- **Coating Antimicrobials to polymers surface**
  waxes with fungicides coating for fruits and vegetables extended shelf life, incorporated quaternary ammonium salts coat in shrink films to wrap potatoes and wrapping of cheese and sausages by coating wax paper and cellulose casing with sorbic acid. Are being used as early development of coated Antimicrobials [38, 39].

APPLICATION OF ANTIMICROBIAL PACKAGING IN FOODS

Antimicrobial packaging besides packaging can have applications in food which includes enhancing the shelf life of food and inhibiting the growth of microorganisms [6]. In addition, an edible film is defined as a packaging material, which is a thin layer placed on or between food component, used as wraps or separation layers(40-41). The main coating techniques used in those materials are described below:

- **Spraying**
  The popularity of spraying has increased greatly in industry have increased greatly not only due to potential cost reduction but also by the high quality of final product [42]. This technique provides uniformity in coating, thickness and multilayer application [43].. On the other hand it combine hydrophobic and hydrophilic substances [44].

- **Dipping**
  This method has been used to form coatings onto fruits, meats , vegetables [45]. It has properties like viscosity and surface tension of the coating to determine the film thickness [46], since this technique is able to form thick coating layer [47]. In this a method a membranous film is formed over the product surface by directly dipping the product into the liquid coating formulation and further air drying [48].
- **Spreading**
  This method, also known as consists of the control spreading of suspension on to the material. The thickness of the coating suspension is controlled by a blade attached to the lower part of spreading device and the film. Drying is held on the support itself, by circulation of hot air [49].

PROPERTIES OF ANTIMICROBIAL PACKAGING

Antimicrobial edible films and coatings have established their ability to protect foodstuff from spoilage and to reduce the risk of pathogens growth by regulating the diffusion and gradual release of surrounded antimicrobial agents onto the food product (50). The selection of the most adequate antimicrobial agents is based on their effectiveness against the target microorganisms, as well as their possible interactions with the film-forming polymers and the packaged food. These connections can be altered by the antimicrobial activity and their own film characteristics, instituting key factors for the development of antimicrobial films and coatings [26].

Various physical tests to regulate the mechanical and barrier properties of edible coatings and films have been stated. Quasi-static tension or puncture tests are applied to edible films to determine mechanical parameters, such as the elastic modulus, tensile strength and strain at break [51]. Water vapor permeability (WVP) of these films is found in accordance with the ASTM E-96 static method. It was found that the resistance of films to water is grave for the potential application of these films, since much food is stored in aqueous solutions.

On the other hand, as a consequence of the generally poor barrier to water vapor and low mechanical strength of biopolymers, some edible films and coatings have still partial applications in food packaging [33].

Antimicrobial properties of edible coatings can be assessed by using various types of microorganisms and different testing methods, including:

i) the film disk agar diffusion assay,

ii) the enumeration by plate count of microbial population and

iii) the film surface inoculation test.

These methods have been applied for the in vitro evaluation of the antimicrobial film's performance. Nevertheless, when coatings are applied onto food, their efficiency as assessed through the enumeration of indigenous or inoculated microbial population during food storage, the result showed that the application of pure chitosan films reduced the pathogen counts on meat products [26].

EFFECTIVENESS OF ANTIMICROBIAL PACKAGING

Plentiful researches evaluated that antimicrobial packaging can efficiently prevent targeted bacteria when suitable amounts of antimicrobial agents are added into packaging materials. The efficacy of antimicrobial packaging is greater in comparison to direct addition of preservative agents into food due to two important reasons. First, the attachment of antimicrobial agents with polymer film enables sluggish release of antimicrobial agents function over longer period. Second, antimicrobial activities of preservative agents may face inactivation by food matrixes and components when added directly into the food [52]. The effectiveness of antimicrobial packaging can be seen in various forms:

Antimicrobial Packaging with Essential oils and Plant Extract

Though essential oils are rich in volatile terpenoids and phenolic particles, they are highly potential in preventing a wide range of microorganisms. Usually, the active components of plant essential oils prevent microorganisms by commotion of the cytoplasmic membrane, electron flow, active transport and inhibition of protein synthesis. Examples of plant extracts and essential oils that most widely combined into food packaging are linalool, thymol, carvacrol, clove oil, cinnamaldehyde and basil essential oils [53].

Antimicrobial Packaging with Enzymes

Lysozyme enzyme, extracted from hen egg white is known as natural antimicrobial agent and commonly added into packaging materials. Gram-positive bacteria are very vulnerable to lysozyme, because their membrane is made up of 90% peptidoglycan where hydrolyzation of β-1-4glycosidic linkage between the *N*-acetyl muramic acid and *N*-acetyl glucosamine takes place. In order to further improve the antimicrobial effectiveness of enzyme, other antimicrobial agents like detergents and chelators are usually added. Lactoferrin a natural component present in milk with large cationic patches were used to improve the activity of lysozyme towards gram-negative bacteria and has been used in antimicrobial spray for beef carcasses (54).

Antimicrobial Packaging with Bacteriocin

A metabolic by-product of antimicrobial peptide, Bacteriocin is generated by bacteria for defence system from almost all types of bacteria and their ability to survive raised temperatures and acidic environment. Bacteriocin is produced by Lactic Acid Bacteria (LAB) has high acceptance from public and being the important bacteria for fermented foods, it is consumed for decades. It included cheese, wine, kimchi, miso, soy sauce, bean paste, *etc*. In a study, Polyethylene film coated withnisin made by blown film extrusion process tested for vacuum packaging of meat inoculated with *Bacillus thermosphacta* has significantly inhibited the growth of bacteria [55].

CONCLUSION

This review underlines the most recent trends in Antimicrobial packaging which is rapidly emerging as newest technology. The necessity to package foods in a adaptable and safe manner for transportation and storage, along with the growing consumer demand for fresh, convenient, and safe food products presents a optimistic future for antimicrobial packaging. This system could prevent the growth of spoilage and pathogenic microorganisms, and contribute to the improvement of food safety and the extension of shelf-life of the food in addition to other barrier. The basic impression behind this technology is the usage of antimicrobial substances in polymeric matrices, which helps in controlling the microbial population and target specific microorganisms in food products with extended shelf life.

To conclude, the current situation demands the necessity of concentrating on future research on the selection of the appropriate antimicrobial agents and the most adequate polymer matrices, to ensure good interactions among them and effectiveness against the target microorganisms.

As an over-all conclusion, antimicrobial edible coatings are ready to assume an effective alternative in active packaging materials to expand the safety of processed food products for commercial purposes.

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