Safety and Quality of Antimicrobial Packaging Applied to Seafood

Abstract

The food industry is developing antimicrobial active packaging to meet consumer demands on ensuring the quality and food safety. Besides the use of good practices during the manufacturing is also necessary to package products in appropriate packaging to protect and conserve food during storage and marketing phases, ensuring the consumer buying a healthy product. Antimicrobial packaging has been used to increase shelf life, prevent deterioration, ensure chemical and microbiological food safety, and inhibiting the growth of pathogenic microorganisms. The addition of antimicrobial compounds contributes to the growth inhibition of fungus and yeast, providing increased safety and quality for the storage and shelf life. The conclusion is that the antimicrobial packaging has potential application in the food market, aiming to ensure and or monitor the quality and safety of these products.

Keywords: Food security; Active packaging; Seafood

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Alex Augusto Gonçalves* and Manuella de Oliveira Cabral Rocha

Department of Animal Sciences, Federal University of Semi-Arid, Brazil

***Corresponding author:** Alex Augusto Gonçalves, Chief of Laboratory of Seafood Technology and Quality Control (LAPESC), Department of Animal Sciences (DCAN), Federal University of Semi-Arid (UFERSA), Av. Francisco Mota, 572, Costa e Silva, 59625-900, Mossoró, RN, Brazil, Tel: + 55 84 33178300; + 55 84 991713135/1419; Fax: + 55 84 33178361; Email: alaugo@gmail.edu.br

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Introduction

Nowadays, a large quantity of seafood is still moved to market essentially unpackaged. Whole or gutted fish are iced in fish holds, stored upon landing and then re-iced in bulk containers to be hauled to local fish markets. At the market, whole, dressed or filleted fish are displayed and offered for sale (still unpackaged) on a bed of ice. A switch from wooden to waxed or plastic-coated corrugated boxes as the bulk shipping container has been the sole packaging improvement in this marketing scheme, and a folded newspaper remains the most common form of final product protection [1,2].

Frozen seafood products have fared somewhat better, judging from a large selection of attractively packaged raw and processed fish products available in supermarket frozen food sections. Unfortunately, the appearance of some packages is better than their ability to protect product quality. Thus, consumers complain about off-flavors and rubbery, watery of otherwise attractively packaged products [1,3-6].

Obviously, the seafood industry continues to grow despite a lack of adequate packaging. However, future expansion of seafood sales will mean moving products through longer distribution chains to reach inland markets. Many processors understand that a package needs to protect the product but do not realize the important role which packaging plays in selling the product. Thus, packaging will play a key role in the shift from shop to supermarket merchandising of seafood, and to ensure high quality, good sales appeal, and consumer satisfaction [1,7].

The consumer is more interested in the product than the package; therefore, a primary function of the package is to provide information about the product. Some consumers, accustomed to evaluating fish quality by smell as much as by sight, may sniff a package in an effort to detect off-odors (flavors). To allow for this inspection, packaging film of intermediate gas permeability may be the best choice for many seafood products. It's limited permeability, however, allows odors to escape sufficiently to prevent accumulation of odors that might be objectionable when the package is first opened, regardless of the freshness [5,6,8]. Thus, the aim of any packaging system for fresh muscle foods is to prevent or delay undesirable changes to the appearance, flavor, odor, and texture. Deterioration in these qualities can result in economic losses due to consumer rejection of the product [9,10].

Recent microbial foodborne outbreaks are causing a search for innovative ways to inhibit microbial growth in foods while maintaining quality, freshness and safety. The deterioration by microorganisms and lipid oxidation are the major cause of food losses. Therefore, controlling the growth of these microorganisms and the lipid oxidation is necessary so that the food reach a high level of quality and safety. One option is to use packages that provide technologies that will play a role in increasing the food shelf life and reduce the risk of contamination by pathogenic microorganisms [11-13].

Typically, food packaging has been designed to protect the product; one of its main requirements is no interaction with the packaged food and thus acts as an inert barrier between the food and the environment [14]. Packaging is one of the most important processes for maintaining food quality during transport, storage, and consumption. It prevents the product deterioration and facilitates the distribution and marketing. The basic functions of packaging are protection, with holding information and convenience [15]. However, the main function of food packaging is to preserve the food quality and safety until reaching the consumer's table. During distribution, the food product quality may deteriorate biological, chemical and physically. Thus, food packaging contributes to increasing the food shelf life and maintenance of quality and safety [8,16].

Any development of novel packaging must address at least four regulatory or food safety criteria: (1) food-contact approval; (2) environmental regulations; (3) a need for labeling (e.g. where the active package may give rise to end-user/consumer confusion); and (4) consideration of the effects of the package on the microbial ecology and safety of the food. The latter is important to minimize the risk of creating an unnatural "micro-climate" within the food package (e.g. an active package that removes oxygen from within the package may also create favorable conditions for the growth of anaerobic pathogenic bacteria) [2].

In the majority of solids or semi-solid food, microbial growth occurs mainly on the surface. In food preparations, microbiological growth can occur anywhere in the mass. Similarly, antimicrobial packaging for food act to reduce, inhibit or retard the growth of microorganisms that may be present in the packaged food [17].

Currently, the study and development of packaging, especially the active packaging (packaging that interact with food) have been essential to increasing the food shelf life. For this, the technologies which involving active packages intended to present desirable interactions with the product, increasing or monitoring its shelf life [18].

Food Packaging

For the maintenance of quality at the seafood chain, adequate packaging should: (1) protect the product; (2) sell the product, and (3) aid in the convenient use of the product. Before discussing the many types of packaging materials and machines available for use with seafood, it is important to consider how each of these important functions pertains to the packaging of fishery products [2,9,19-21]. Convenience is not just a function of how the product is prepared prior to sale (raw whole, fillet, breaded portion, smoked slices, etc.), but also of the package construction and function. Packages can protect, help the product sell, and contribute to easy handling and preparation as well [6,8].

Handling characteristics should be considered and include the performance characteristics of the packaging materials during the actual packaging process (often called machinability characteristics of the material) as well as the strength and durability of the material when it is in contact with irregular product surfaces and/or when it is subjected to physical abuse in normal distribution. The characteristics that may be important, depending on the type of packaging equipment used, could include tear strength, stretchability, shrink ability, slippage, and heat-sealing or closure-sealing capacities. The toughness of the packaging material is usually a function of cost for a given category of packaging materials, whether clear film, paperboard, metal foils or rigid plastics. For cost effectiveness, the materials selected should only be durable enough to provide the level of package protection needed at a particular stage of distribution [6,20].

The main focus to food packaging designers and engineers (i.e., product shelf life, overall appearance, and its quality) is the surface properties of food packaging polymers. Among them, can be cited the wet ability, scalability, printability, dye uptake, resistance to glazing, and last but not least the polymers or food surfaces' adhesion. The most commonly used food packaging polymers are LPDE (low-density polyethylene), HDPE (high-density polyethylene), PP (polypropylene), PTFE (polytetrafluoroethylene), and nylon; that have been extensively studied [2,5].

Barrier protection in opposition to the microorganism's invasion is the major function of extended shelf-stable food packaging. There has been more research and development regarding to the introduction of new purposes to food packaging systems beyond the barrier function, like as active packaging, modified atmosphere packaging (MAP) and edible films/coatings [8,10,13,22,23].

Another significant issue in food packaging is that it should be natural and environmentally friendly. The substitution of artificial chemical ingredients in foods and in packaging materials with natural ingredients is always attractive to consumers. Many ingredients have been substituted with natural components (chemical antioxidants such as butylated hydroxyanisole - BHA, butylated hydroxytoluene - BHT, and Tertiary butylhydroquinone - TBHQ) have been replaced with tocopherol and ascorbic acid mixtures for food products, and are be used in food packaging system design areas. To design the ecological packaging systems, for example, partial replacement of synthetic packaging materials with biodegradable or edible or recyclable or reusable and refillable materials are necessary [8,16]. Biopolymer films have been used as an environmental friendly material. However, a central limitation that needs to be overcome is the hydrophilicity of the components in order to allow such replacement. The improvement of biopolymer films water barrier ability depends on the addition of waxes, fatty acids, and lipids [5,24,25].

When it comes to improvements in safety, quality and productivity of new packaging, both the equipment and the production process should follow standards, and when included in the process new functions for packaging, this should follow the same path. The new packaging technologies that are being developed seek not only new materials but also new packaging design systems [8,19,26].

Packaging Applications

During recent years, there has been a greatly increased consumer demand for perishable chilled foods, which are perceived as being fresh, healthy and convenient. The major food retailers have satisfied this consumer demand by providing an ever-increasing range of value-added chilled food products. The wide diversity of chilled foods available is accompanied by a huge range of packaging materials and formats which are used to present attractively packaged foods in retail chill cabinets [1,7,27].

Even when chilled, fishery products are among the most perishable food products known. At least three mainly factors contributing to this rapid loss of quality: (1) enzyme attack (several digestive and muscle enzymes of fish and shellfish actively break down muscle proteins, which may result in soft, mushy textures); (2) bacterial growth (fishery products are an excellent

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source of nutrients for bacteria, which convert these nutrients into foul-smelling compound); and (3) fat oxidation (fats and oils of fishery products are unsaturated and tend to break down easily into rancid compounds) [1,6,7].

The action of enzymes can be controlled only by maintaining the product at temperatures as low as possible. Packaging cannot be expected to help much in this respect, except as an insulator during shipment. Low temperature is also essential to minimizing bacterial growth, and packaging can play a key role in its inhibition by controlling the exposed environment (i.e. modified atmosphere - vacuum) [6,28].Although frozen fish are not subject to spoilage by the bacterial attack, fat oxidation (only in lower velocity), and enzyme activity, moisture migration does contribute to a quality loss in many cases. It's necessary the maintenance of a low storage temperature with few temperature fluctuations (such as may be caused by cycling of refrigeration equipment) to help control these factors [3,7,29].

Packaging can play an important role in preserving quality within frozen foods (i.e. can control fat oxidation and moisture migration very effectively). By selecting the appropriate material and design of the package, the food producer can help to protect the food product from damage and loss of quality during its distribution from the factory to the consumer. The packaging also makes a key contribution in minimizing quality loss within the food during periods of frozen storage [2,19].

Requirements

The primary function of food packaging is to protect the food from external hazards. At the same time, the packaging material itself should not affect the food in any way. The packaging material chosen should meet certain minimum technical, legislative, environmental and commercial requirements. Many of these requirements are intended to ensure that the packaging material provides the product with the necessary protection to ensure both food safety and quality. The capacity of packaging to provide an effective barrier to the ingress of moisture, gasses and contaminants from the environment to the food is essential for preserving both sensory and nutritional characteristics. Similarly, suitable packaging has the ability to provide an effective barrier to the loss of moisture and flavor volatiles from the food to the external environment [19,30].

For chilled product, visibility is important. Clear films with no fogging and dry, fresh-looking product make the best first impression. Consumers like to inspect as much of the product as possible to determine quality. When packaging many fish species, lay fillets with both skin side up and meat side up so the buyer can make rapid species identification and an adequate quality inspection [2]. For frozen product, visibility is also important. Transparent films also may be used with frozen fish to heighten the visual impact and quality image. The film should be skin tight with no frost accumulation within the package [19].

The packaging material must contain the food without leaking, be non-toxic and have sufficient mechanical strength to protect the food and itself from the stresses of manufacture, storage, distribution and display. Certain packs require a degree of porosity to allow moisture or gaseous exchange to take place, and packaging materials used in these situations should possess appropriate permeability properties. Alternatively, most modified atmosphere packs require moisture and gasses to be retained within the pack and hence the packaging materials used should possess appropriate barrier properties. The specific requirements for modified atmosphere packs are described later. Depending on the type of chilled food product, the packaging material may need to be tolerant of high temperatures experienced during hot filling, in-pack pasteurization or reheating prior to consumption. The packaging material, particularly with high-speed continuous factory operations, may need to be compatible with form–fill–seal machines. The pack closure must have seal integrity but at the same time should be easy to open. There may be a need for reclosure during storage after opening in the home. In addition, with the increased incidence of malicious contamination, the tamperproof or tamper-evident packaging is desirable. The package is the primary means of displaying the contained chilled food and providing product information and point-of-sale advertising. Clarity and printability are two pertinent features that require consideration in the choice of materials [8,27].

With almost any package of chilled seafood, a dry appearance improves the quality image. Product wee page is best controlled by constantly maintaining the product near 0°C or below and using an absorbent pad. "Fog" accumulation, which hides the product from view, can be controlled by coating the underside of the package film with a wetting agent to prevent water droplets from forming. Wet packs of such seafood as oysters and scallops commonly consist of round containers of either metal, plastic, or coated paperboard, with snap-on or crimped lids. The product should be visible through the lid or a side window made of a clear plastic. The rectangular, rigid, heat-sealed containers previously mentioned also make an attractive wet pack. These may be clear or opaque with the product clearly visible through the top film [2,6].

Active systems

Due to recent outbreaks of contaminations associated with meat products, as well as growing concerns regarding the safety of intermediate moisture foods, active packaging (AP) has been greatly developed in recent years [24,27,31,32]. The term "active packaging" was first applied by Labuza and Breene [12] and may be defined as packaging which performs some desired function other than merely providing a barrier to the external environment. Active packaging should not be confused with "intelligent packaging", which informs or communicates with the consumer regarding the present properties of the food, or records aspects of its history [10,20,33-35].

As mentioned in Quintavalla and Vicini [33] a packaging material is defined as "a type of packaging that changes the condition of the packaging to extend shelf life or improve safety or sensory properties while maintaining the quality of the food" [24,27]. Thus, Rooney [34] conceptualizes active packaging, as packaging that not only separates the food from the environment but which interacts with the food to maintain their properties. According to Scannel et al. [36] active packaging is an innovative concept that combines advances in food technology, food safety, and packaging materials in an effort to better meet the demands of consumers for fresh and safe foods.

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Active packaging can be defined as performing some desired role in food quality or safety other than to provide an inert barrier to external conditions. Specific reasons for developing active packaging are summarized as follows: (1) removal of an unwanted component; (2) addition of the desired ingredient; (3) package surface antimicrobial activity; and (4) changed physical properties of the package [20,35].

The decision to consider active packaging for a food or beverage is commonly based on factors typically involved in any package selection. These considerations include economic advantage, process-engineering limitations, convenience in use, environmental impacts, and secondary effects resulting from some other change in the processing or packaging. The latter effects may result from new product introduction due to lifestyle changes or the availability of technologies that remove a limitation formerly experienced [2].

AP is the incorporation of specific compounds into packaging systems that interact with the contents or environment to maintain or extend product quality and shelf life, while intelligent or smart packaging provides for sensing of the food properties or package environment to inform the processor, retailer and/or consumer of the status of the environment or food [10,15].

There are many applications of active packaging technologies, several of which have been commercialized and are used in the food industry. The new design of a more active packaging include the antimicrobial polymers [37,38], oxygen absorbers [39], oxygen scavenging, carbon dioxide-absorbing, moisture-scavenging (desiccation), CO2 releasing and immobilized enzymes on polymeric supports, such as lysozyme [17], and others [8,10,20,24,27,31-33,35].

Some requirements for AP production are linked to the plastic extrusion stages, during the package development, or when the pack is filled and sealed. Care and control should be done when antioxidants (or other additives) are been used or added during extrusion process, because the instability of these additives during the extrusion temperatures (200-370°C). The suggestion is to apply them directly to the packaging (as internal coatings) [34].

When an edible films and coating contributes to the packaging of a food, the coating performs first as a food component [10,22,25]. However, because it is normally made from one or more food constituents it may need protection against the microbial activity. Hence, if a mobile antimicrobial agent is incorporated therein, the coating can serve several functions, like as: self-preservation, helping to reduce the microbial load on the food surface, and providing an outer surface with antimicrobial properties.

The additional information of foods that use edible coatings can be very complex, so considering the formulation of the coating, the importance of the involved additive (i.e., it's active contribution) should be considered [10,13,40].

Active substances carried through edible films or coatings has been suggested as a promising application of active food packaging. In fact, the use of edible films and coatings for food packaging without active substances is arguably also an application of active food packaging, since the edibility and biodegradability of the films are additional functions not offered by conventional packaging materials [31,32,41].

Oxygen is responsible for many degradation processes in foods, which are commonly delayed with the application of antioxidant agents. The inclusion of strongly flavored antioxidants (essential oils, N-acetylcysteine, glutathione, etc.) in edible films and coatings allow for their encapsulation and reduces their strong aroma. Additionally, films and coatings through their oxygen barrier effect could effectively reduce oxidation, which is highly dependent on the water availability. This work reviews the latest studies on the antioxidant effect of edible films and coatings [24].

The antioxidant effect of edible films is strongly linked to their oxygen permeability. Films made from proteins and carbohydrates are excellent barriers to oxygen, because of their tightly packed, ordered hydrogen-bonded network structure [42]. The oxygen permeability of edible materials depends on many factors (temperature, thickness, etc.), and is highly dependent on the relative humidity, as corroborated by Hong and Krochta [43].

As relative humidity increases, more water molecules interact with the material and the film becomes more plasticized. In these conditions, the mobility and the extensive mass transfer across the film are favored. For this reason, the antioxidant ability of edible films should always be tested under controlled relative humidity [24].

In dry conditions (low moisture products), the network structure of the film or coating is tightly packed and its oxygen permeability is very limited. This mechanism by itself may have positive effects on the preservation of the quality, because of the reduced oxygen availability in the coated product. In some cases, the addition of antioxidants can entail further protection due to the enhancement of the oxygen barrier properties of the film. However, in these conditions of reduced mobility the actual chemical activity of the antioxidant agents is masked by the oxygen barrier effect. On the other hand, in wet systems, the coating network is plasticized and mass transference is favored. In this context, the oxygen permeability of the film or coating is dramatically increased and the specific activity of antioxidant agents could become more relevant [2,24].

Antimicrobial packaging (AP): As mentioned earlier, the deterioration by microorganisms and lipid oxidation are the major cause of food losses and the control of the growth of these microorganisms and the lipid oxidation is necessary for reach a high food quality; thus increasing the product shelf life and the industry profitability. The release of additives for active packaging increase the consumer safety, because these compounds, rather than directly added to the food, are controllably released, and thus, are present in smaller quantities, and only where its presence is required - on the product surface - where most of the degradation reactions occur [2]. The main component of most food packaging systems should be summarized as: i) food product, ii) headspace atmosphere, and iii) packaging materials. The increase on the antimicrobial efficiency can be reached if one of these three components possesses an antimicrobial substance [11,16,40].

The antimicrobial packaging has been considered one of the most promising innovations among the active packaging technologies, such as oxygen-scavenging packaging and moisture-control packaging [16,44]. The incorporation of antimicrobial substances in food packaging materials to control the undesirable growth of microorganisms on the surface of food is an extremely challenging technology that could extend shelf life and improve food safety in both synthetic polymers and edible films [10,11,27,45].

AP applications are directly related to food microbial safety and bioterrorism, as well as to shelf-life extension by preventing the growth of spoilage and/or pathogenic microorganisms, and enhance the safety of packaged products. The growth of spoilage microorganisms reduces the food shelf life, while the growth of pathogenic microorganisms endangers public health. Antimicrobial packaging systems consist of packaging materials, in-package atmospheres, and packaged foods, and are able to kill or inhibit microorganisms that cause food-borne illnesses [8,13,16,33,45].

Antimicrobial films can be defined as five basic categories as follows [2,10,24,40]: (1) Incorporation of the antimicrobial substances into a sachet connected to the package from which the bioactive substance is released during further storage. Common packaging materials can be utilized without the use of alternative packaging materials; (2) Direct incorporation of the antimicrobial into the packaging film. When applied to a hot extrusion material, thermoresistance and shearing resistance of the antimicrobial must be considered; (3) Coating of the packaging with a matrix that acts as a carrier for the additive or antimicrobial agent. The substance will not be submitted to high temperature or shearing forces; moreover, it could be applied as the later step; these categories of materials can release the antimicrobial agents onto the surface of the food. The antimicrobial agents may either be released through evaporation in the headspace, considering the presence of volatile substances, or migrate into the food system by non-volatile additives, through diffusion. The lower migration of the agents away from the food surface helps the maintenance of higher concentrations of antimicrobial agents that are needed; (4) Utilization of inherently antimicrobial polymers that exhibit bioactive properties which release the biocide agent into food products. The mains concern is the limitation of such a system is the direct contact between the packaging and the food; (5) Utilization of bioactive edible coatings directly applied onto the foods. The limitation is that the bioactive agent should be approved as a food additive.

There are various factors to be considered in designing antimicrobial systems and can be constructed by using antimicrobial packaging materials, antimicrobial inserts (such as sachets) to generate antimicrobial atmosphere conditions inside packages or antimicrobial edible food ingredients in the formulation of foods. Since antimicrobial packaging systems are designed to control the growth of microorganisms in packaged foods, the systems essentially consist of packaging materials (or packages), foods, the in-package atmosphere, target microorganisms, and antimicrobial agents. These five elements are related to one another and to the final system design features [11,16,24,40].

The most common chemical antimicrobials used by researchers are the various organic acids. Organic acids are widely used as chemical antimicrobial agents because their efficacy is generally well understood and cost effective. Many organic acids, including fatty acids, are naturally existing chemicals and have been used historically. Currently, most of them are produced by chemical synthesis or chemically modified from natural acids. Organic acids have characteristic sensitivities to microorganisms. Therefore, the correct selection of organic acids is essential to have effective antimicrobial agents. Mixtures of organic acids have a wider antimicrobial spectrum and stronger activity than a single organic acid [10,11,16,24].

An antimicrobial agent has specific inhibitory activity and mechanisms against each microorganism. Therefore, the selection of antimicrobial agents is dependent on their efficacy against a target microorganism and it is strongly recommended that experiments regarding the efficiency examination of an antimicrobial packaging system should be conducted using a real food instead of culture broth or agar media [16].

a. Interactions between the antimicrobial activity and food: Currently, studies has been developing on antimicrobial active packaging which is based on incorporation of preservatives in the polymer structure that comprises films, labels, tags or sachets to reduce, inhibit or retard the growth of microbial flora mainly on the surface of the packaged food (which occurs the most of the degradation reactions) [46,47]. Their addition to the polymeric films can be done in two ways: incorporation and immobilization. In the first case, the antimicrobial agent is released from food, while the second case, the compound acts only in the surface level [16,18].

The necessary requirement for the antimicrobial packaging operation is the intense contact with the food, which restricts the number of compounds to be used for its manufacture since the contact can not cause any contamination or leave residue on the food. The antimicrobial packaging can be divided into two groups: i) the antimicrobial agent migrate from the package to the product surface; ii) the agents are effective against surface microbial growth without the necessity to migrate to the product [46,48].

A major advantage in the use of incorporated antimicrobial agents is to allow a reduction in the level of food preservatives, serving to the consumer trends which are seeking for minimally processed foods and with minimum levels of additives [46,49]. When the antimicrobial is released from the package over time, the kinetics of microbial growth and antimicrobial activity on the product surface can be balanced. Thus, the antimicrobial activity of the package can be extended to ensure safety during food distribution [17,33,46].

Then the use of active packaging can ensure the better efficacy of the bactericidal or bacteriostatic compound, for having slow agent diffusion from the package to the food surface, assisting the maintenance of higher concentrations at the products surface [33].

b. The antimicrobial agent choice: It should be considered in selecting the antimicrobial agent, the mechanism of inhibition, physicochemical characteristics, the agent migration and diffusion kinetics into the food, type and microorganism population, physiology of the target microorganism, packaging material manufacturing process, processability of the packaging material and related legislation [46].

Some factors may affect the effectiveness of antimicrobial packagings, such as the antimicrobial characteristics (solubility and molecular size) and food characteristics, conditions of distribution and storage (time and temperature), the film preparation method (extrusion or casting) and interaction between antimicrobial and polymer [50,51].

Conclusion

Some of the most important forms of active packaging have been highlighted, indicating that this field is no longer merely a scientific curiosity. The growth has been largely in the areas of food quality as affected by microbiological and oxidative effects.

The incorporation of antimicrobial substances in food packaging materials to control the undesirable growth of microorganisms on the surface of foods is one the most promising innovations in food packaging.

Antimicrobial packaging systems is an extremely challenging technology that could 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 in both synthetic polymers and edible films.

Many factors are involved in designing the antimicrobial packaging system; however, most factors are closely related to the characteristics of antimicrobial agents, packaged foods and target microorganisms. Even though most packaged perishable food products are heat sterilized or has a self-protecting immune system, microbial contamination could occur on the surface or damaged area of the food through package defects or re-storage after opening. The antimicrobial substances incorporated into packaging materials can control microbial contamination by reducing the growth rate and maximum growth population and extending the lag period of the target microorganism.

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Conflict of Interest

The Authors wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

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