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# Antimicrobial coatings and films on meats: A perspective on the application of antimicrobial edible films or coatings on meats from the past to future

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## ABSTRACT

**Background:** Edible coatings have responded to demands concerning the production of biodegradable and environment-friendly packages. Incorporation of antibacterial materials into edible films provides a valuable protective agent against spoilage of meats. Fish, poultry, and red meats due to their high nutritional contents are suitable for bacterial growth and can be preserved a few days in a refrigerator.

**Aim:** This study aimed to investigate the importance of antimicrobial edible coatings or films on meats. In this regard, the types, effects, and traits of edible films, types of antibacterial substances incorporated into films or coatings, bacterial diversity of meats and the function of antibacterial films from the past when collagen-like substances were used on sausages to future trends, including the application of nanoparticles in coatings have been discussed.

**Results:** Applying antibacterial edible films or coatings on meats to extend the shelf life of meats and meat products.

**Keywords:** Edible film, Edible coating, Antibacterial, Meat, Shelf life

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## INTRODUCTION

Meats are a main source of protein in a human diet. An enormous amount of meats, including red, poultry, and fish meats are produced, maintained and consumed every day. The high content of nutrients makes meats the best environment for microorganisms to grow. Meat is a perishable commodity and can be preserved a few days in a refrigerator. So, preserving the meats to maintain quality for a longer time has been of interest to producers and processors.

Edible coating or films serve as an alternative emerging technology to increase the shelf life of food products. Edible coatings or films, although possess limitations to substitute synthetic packages, have unique properties such as biodegradability, consumption feasibility, and is free of chemical substances. One of the most important functionality of edible films is that they can serve as vehicles to incorporate antibacterial agents. The presence of antimicrobial materials in coatings or films increases the shelf life of food, especially meats. Antibacterial substances reduce the proliferation of spoilage organisms during storage in refrigerated condition. Thus the meat remains fresh for a longer time.

Antibacterial components incorporated into edible coatings or films can reduce the microbial contamination by extending the lag-phase or inactivating target microorganisms.

### A brief history of edible films and coatings application on meats.

The application of coatings and films as edible components of foods is not new, and the antiquity of them dates back to the nineteenth century. Table 1 provides examples of edible coatings and films in meat products.

### The application of polysaccharide, protein, and lipid films and coatings on meats.

Meats such as red meat, poultry, or seafood, because of their perishable nature, should be preserved. The common agents of decomposition in meat products include oxidation, microbial contamination, off-flavors, and discoloration. Direct coating with protective solutions or packaging with edible films has a long track of use application in the food industries.

Edible films and coatings can be made from proteins, lipids, polysaccharides, or in the composite form of them. Some protein films used on meats are collagen, gelatin, zein and whey proteins. Alginate, chitosan, cellulose, and starch are commonly used as polysaccharide films. The lipids applied on various meats comprise of acylglycerol, waxes, and fatty acids.[1]

**Table 1 Examples of edible coatings and films usage on meats in the past**

| Types of edible coatings and film substances | Functionality | Reference |
|---|---|---|
| Collagen or collagen-like substances (1936-1939). | Increasing the shelf life of sausages | Oskar,[80] Oskar,[81] Oskar[82] |
| Carrageenan-based coatings (1949 and 1959). | Extending the shelf life of poultry | Pearce, Layers,[83] Meyer, Winter, Weiser[84] |
| Wax layers as edible films (As recently as 1967). | Preserving fruits for longer time | Embuscado, Huber[85] |
| Molten wax (As early as twelfth century). | Citrus fruits were maintained by placing in molten wax boxes and sent for the Emperor's table by caravan from Southern China to the North | Hardenburg[86] |
| Alginates, gums, fats and starches edible films (1960s). | extending the shelf-life of frozen meat, poultry and seafood | Earle,[87] Earle, Snyder[88] |
| Fats or waxes as | Storing various fruits in Europe as "larding" method | Labuza, Contreras-Medellin[89] T </author><author>Contreras-Medellin, R </author></authors> </contributors><titles><title>Prediction of moisture protection requirements for foods </title><secondary-title>Cereal Foods World (USA |
| Yuba edible film | Utilization of Yuba as an edible film made from skin of boiled soy milk in Japan for preserving food quality and appearance. | Biquet, Guilbert,[90] Gennadios, Weller, Testin[91] |
| Gelatin (nineteenth century). | Introducing gelatin as a coating or film for preservation of diverse meat products | Havard[92] |
| Some kind of sugary coatings like chocolate (1988). | using in confectionaries | Biquet, Labuza[93] |
| Fat coating (sixteenth century). | preventing the shrinkage of meats | Kester, Fennema[94] |
| Sucrose (nineteenth century). | Preventing nuts, hazelnuts and almonds from oxidation and rancidness during storage | Debeaufort, Quezada-Gallo, Voilley[18] |
| Incorporation of antifungal and antibiotic compounds into carrageenan film (1959). | Reducing bacteria and fungi growth | Meyer, Winter, Weiser[84] |
| Sorbic acid and potassium sorbate (1990). | Application as antimicrobial agents into edible films. | VOJDANI, TORRES[95] |
| Chitosan film with organic acids (In the 1990s). | Introducing a new antimicrobial film | Gennadios, MCHUGHC, WELLER[96] |
| Calcium alginate film incorporated with organic acid (1993). | reducing *L. monocytogenes*, *E. coli* O157:H7 and S. typhimurium levels on beef carcasses | SIRAGUSA, DICKSON[97] |
| Lysozyme (1994). | Lysozyme was used as an antimicrobial component in many studies for production antimicrobial edible coatings and films | Gennadios, MCHUGHC, WELLER[96] |
| Replacing of lactic acid with glycerol in a pectin film (1996). | preventing the fungal growth without significant change in mechanical properties | Hoagland, Parris[98] |
| Diffusible substances (2002). | Increasing the antimicrobial activity of edible coatings | Appendini, Hotchkiss[99] |

### *POLYSACCHARIDE BASED EDIBLE FILMS/ COATINGS*

Polysaccharide films usually have visual appearances which make them desirable for use as a coating on meat products. These kinds of coatings have three main advantages, possessing an oxygen barrier property, acting as a sacrificing agent, and creating a spectacular appearance.

Wu et al.[2] showed that the application of starch-alginate composite films significantly ($p < 0.05$) reduced the moisture loss and the lipid oxidation of ground-beef patties compared to the control samples (without edible film) during six days. Numerous papers associated with the effect of polysaccharide coatings or films on moisture loss and the fat oxidation of meats have been published.[3,4] The hygroscopic nature of polysaccharide films makes them resistant to moisture loss. In spite of this benefit, polysaccharide based films are permeable to water. The other advantage of such coatings is their protective ability against gas penetration, especially oxygen. The presence of the high oxygen concentration around the meats has undesirable effects such as lipid oxidation or bacterial spoilage. Films made from the pea starch or the high-amylose rice are excellent oxygen barriers.[5] Hartman et al.[6] developed a film containing hemicellulose O-acetyl-galactoglucomannan combined with alginate or carboxymethylcellulose, which exhibits excellent mechanical strength and oxygen barrier properties. Generally, starch-based coatings are recognized as oxygen barriers.[7]

Another interesting role of polysaccharide coatings is their sacrificing attribute. Carrageenan or alginate solutions were found to form a structured gel on the foods, which intentionally absorb water and provide protection against excessive moisture loss.[8] This function has been known as "sacrificing agent." Williams et al.[9] preserved the moisture of beef cuts coated with calcium alginate by using this feature. In relation to appearance, polysaccharide films are typically colorless or slightly yellow. In addition, the films are free from problems such as oxidative reaction or Maillard which created bad colors on meat.[10]

### PROTEIN BASED EDIBLE FILMS/COATINGS

Protein-based films or coatings are the most widely used material among the biodegradable coatings. They have created a boom in interest over the past 20 years. The inherent properties of proteins have allowed them to become excellent materials for producing films and coatings. The distribution of charge in proteins owing to the polar and non-polar domains creates various chemical abilities. Longer lifetime, creating a cohesive matrix, emulsifying, resisting to water penetration, radical scavenging and antihypertensive features (due to the bioactive peptides)[11] make proteins the perfect film substances.

It has been shown that pink salmon fillets coated with egg albumin (EA) and soy protein concentrate (SPC) had significantly ($P < 0.05$) higher moisture after thawing compared to uncoated fillets.[12] Application of the whey protein substrate as a coating is widely investigated in papers. Many of the researchers indicated that protein based films like whey or milk proteins have an antioxidant impact on the meats.[13,14] Another distinct advantage of the protein based films is their mechanical stability. The roles of proteins in preserving the integrity of edible films on meats have been approved in many studies.[15,16] Cross-linked protein films in comparison with polysaccharide-based counterparts are often more stable.[17] Some protein compounds beget more functional traits than usual. For example, wheat gluten (WG) based films have rubber-like mechanical and selective gas barrier properties. WG films or coatings are transparent, homogeneous, and mechanically strong. The results of WG films application on the beef patties demonstrated in this coating was as effective as polyvinyl chloride films in reducing moisture loss. In another study, it was displayed that WG films reduced hexanal values and thiobarbituric acid-reactive substances (TBARs) compared to control specimens.[4]

### LIPID BASED EDIBLE FILMS/COATINGS

The main purpose of developing hydrophobic coatings such as lipids was to limit the moisture migration from foods. However, they have other benefits such as gas permeation controlling and flavor releasing. In food industries, lipid based coatings are applied to reduce surface stickiness and improve appearance attributes (color, gloss, and sheen).[18] Despite these advantages, wax, oil, and fat-based coatings have high thickness, lack of homogeneity, cracking, greasy surface, and organoleptic problems (waxy taste and rancidity).

Few papers can be found regarding the application of waxes, oils, and fats as protective coatings for meats. McNally[19] dipped whole chickens into the corn oil, molten wax, mineral oil, and lard prior to freezing. All coatings reduced the moisture loss from the frozen chickens, although, the result for mineral oil and wax was better. In another work, a substantial reduction in moisture loss from freeze-dried meats during storage was reported after the molten fat at a temperature of 52 to 79°C was sprayed on the meat.[20]

Lipids are often used in a composite form with hydrocolloids or proteins since the pure lipid films are brittle and have poor elasticity and strength. The composite configuration of hydrophilic and hydrophobic substances provides both mechanical and barrier properties.[21] Composite films are formed by emulsification or by laminating two or more edible films.[22,23]

Ben and Kurth[24] made a casein–lipid composite film, which improved the juiciness and appearance of meat. Ojagh et al.[25] incorporated the cinnamon oil as an antioxidant with chitosan film. His results indicated that the application of chitosan and cinnamon oil composite film on rainbow trouts significantly decreased TBARs and peroxide value during refrigerated storage. Table 2, indicates a number of features of the edible coatings and films on meat products.

**Table 2 Some benefits offered for edible films and coatings (on meats)**

| Film or coating type | Functionality | References |
|---|---|---|
| **Polysaccharide based edible films or coatings** | | |
| Sodium alginate coating | Improved the chemical, microbial and organoleptic properties of buffalo meat patties. | Keshri, Sanyal[100] |
| Pectin coating | Increased the moisture content and reduced the TBARS and microbial population of irradiated pork patties. | Kang, Jo, Kwon, Kim, Chung, Byun[101] |
| Chitosan–gelatin coating | Decreased total volatile basic nitrogen (TVB-N) and gram-negative bacteria count compared to uncoated fish samples. | López-Caballero, Gómez-Guillén, Pérez-Mateos, Montero[102] |
| Chitosan film | Significantly reduced ($p < 0.05$) the moisture loss of herring and Atlantic cod along with a decrease in lipid oxidation. | Jeon, Kamil, Shahidi[103] |
| **Protein based edible films or coatings** | | |
| Gelatin coating | Reduced significantly and a slight color deterioration of coated beef and pork, respectively. | Antoniewski, Barringer, Knipe, Zerby[104] |
| Collagen coating | Incorporating frankfurters with concentration of 0, 1, 2, and 3% pork collagen increased cooked yield and decreased the amount of purge. | Prabhu, Doerscher, Hull[105] |
| Whey and soy protein coating | Retarded the formation of conjugated dienes and malondialdehyde in pork patties as indicators for lipid oxidation | Peña-Ramos, Xiong[106] |
| Sodium caseinate film | Reduced the lipid oxidation of cooked turkey breast meat and augmented the acceptability of sensory evaluation. | Caprioli, O'Sullivan, Monahan[107] |
| **Lipid based edible films or coatings** | | |
| Acetylated monoglyceride or diglyceride coatings | Prevented primal meat cuts from adherence to cellulosic coating | Hill Jr Rufus[108] |
| Acetylated monoglyceride | Coated silver salmon fillets showed less peroxide value and lost less moisture compared to uncoated samples. | Hirasa[109] |

## Microbial quality of meats, poultry, and seafood

There is no doubt that microbial contamination is the most important factor that influences meat spoilage. The number and types of the microorganisms contaminating the meats are related to the several factors including (1) physiological status of the animal; (2) sanitary condition of meat source; (2) slaughter, processing, and handling circumstance; (3) microbial load of ingredients added to the meats; and (4) the subsequent storage and distribution conditions. In fact, the bacteria originated from the environment and processing steps are traced as well as those existing in intestine.[26] In general, microorganisms found in fresh meats are originated from water, air, soil, feed, hides, organs, intestines, processing equipment, and humans.

In association with the types of microorganisms existing in fresh muscle foods, many articles have been published.[27,28] The range of some important microbial species found in fresh and processed meats has been given in Table 3.

It is obvious from the table 1, the common contaminants of red meat carcasses are gram-negative rod bacteria, including *Pseudomonas* spp., *Enterobacter* spp., and *Shewanella putrefaciens*.[29] Also, among the gram-positive bacteria, lactic acid producing microorganisms are common in meats. In poultry, contaminant bacteria are similar to red meats and include mesophilic aerobes ($10^2$-$10^5$.cm$^{-2}$), Enterobacteriaceae ($10^3$- $10^4$.cm$^{-2}$), psychrotrophs ($10^1$-$10^3$.cm$^{-2}$), *E. coli* ($10^1$-$10^5$.cm$^{-2}$), *C. perfringens* ($<10^2$.cm$^{-2}$), *S. aureus* ($10^3$.cm$^{-2}$), *Salmonella* ($<30$.g$^{-1}$), *C. jejuni,* and *L. monocytogenes*.[30-32] In relation to seafood, the initial type of bacteria depends on its origin. Cold water-fish's organisms are generally gram-negative psychrotrophs like *Pseudomonas*, *Shewanella*, *Moraxella*, *Acinetobacter*, *Aeromonas,* and *Flavobacterium* while fishes of the tropics are usually contaminated with gram-positive mesophiles, including *Micrococcus* and *Bacillus* spp.

Microbial spoilage causes various changes in meats consisting of the slime formation, changes in pH, degradation of components, off-odors, off-flavors, and changes in appearance.

Regarding the fact that the most dominated spoilage bacteria in meats are comprised of gram-negatives, it is important to incorporate the major antibacterial components into edible coatings or films that act against these organisms.

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**Table 3 Genera of bacteria found on meats and poultry[110]**

| *Microorganisms* | Gram reaction | Fresh | Processed |
|---|---|---|---|
| *Acinetobacter* | – | XX | X |
| *Bacillus* | + | X | X |
| *Brochothrix* | + | X | X |
| *Campylobacter* | – | X | |
| *Citrobacter* | – | X | |
| *Clostridium* | + | X | |
| *Enterobacter* | – | X | X |
| *Enterococcus* | + | XX | X |
| *Escherichia* | – | X | |
| *Flavobacterium* | – | X | |
| *Lactobacillus* | + | X | XX |
| *Lactococcus* | + | X | |
| *Listeria* | + | X | X |
| *Micrococcus* | + | X | X |
| *Proteus* | – | X | |
| *Pseudomonas* | – | XX | X |
| *Shewanella* | – | X | X |
| *Staphylococcus* | + | X | X |
| *Streptococcus* | + | X | X |
| *Vibrio* | – | X | |
| *Yersinia* | – | X | |

X = known to occur, XX = most frequently isolated

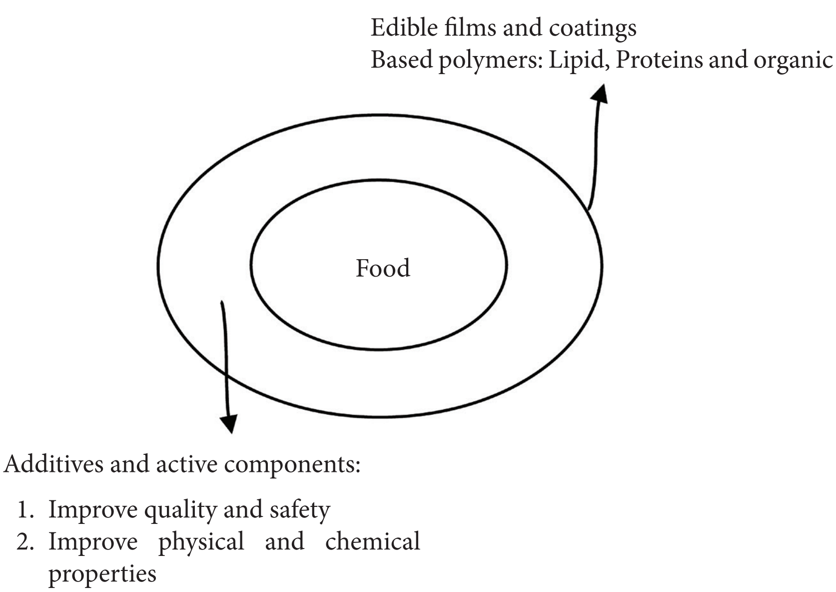


**Figure 1** Edible films' and coatings' compositions

## The characteristics of the most popular antimicrobials used in films or coatings in meat products

Recently, the high prevalence of microbial food disease are the propulsion factor for an innovative way to control microbial activity and maintain quality and safety of the food.[33] Consumers have expected consumed food to be safe, additive free, and also have high a shelf life.

In some fresh products, the highest level of microbial contamination has existed on the surface of the products. The incorporation of antibacterial materials and edible films or coatings has been recognized as a big leap in decreasing the spoilage and pathogenic bacteria in meats.[34,35] The impact of antimicrobial films, due to the migration of bacteria to the surface of foods, can be more efficient than incorporating these materials directly to foods (without edible films).[36] Such coatings or films reduced the growth rate of microorganisms.[35,37] By using different ingredients, for example, proteins, lipids, organic acids, or their combinations, edible films and coatings with antimicrobial properties can be produced.[38-40]

Antimicrobial films are divided into two groups:

1. Antimicrobial films with the ability to migrate antimicrobial agents into the food
2. Antimicrobial films without any migration capability, in fact, they can decrease the bacterial growth on the surface without any migration of substances.[37]

Meat products are the important sources of animal proteins for human. According to Codex Alimentarius,[41] meats have defined as "all parts of an animal that are safe and fit for human consumption." The amounts of meats consumption in 2014 are 108.9, 87, 142, and 287 million tons of pork, poultry, fish, and seafood, respectively.[41] The meat industry has a significant impact on the national economy and marketing systems. Hence, antimicrobial edible films and coatings can be a good choice for increasing the shelf life of meat products and reducing the economic losses.[35,37]

In the following sections, some antimicrobial agents applied on meats has been introduced.

## Organic Acids

Edible films and coating can be having antimicrobial functionality with antimicrobial agents. Organic acids are "Generally Regarded as Safe" (GRAS), either exist naturally in fruits and vegetables or synthesized by microorganisms via fermentation.[42] In addition, they have some advantages such as low-cost and simple to manipulate without any changes in organoleptic characteristics in meat and poultry products.[42]

Organic acids in the undissociated form have an important role in controlling the microbiological quality of meats and meat products. This type of organic acids can penetrate to the cell membrane easier than the ionized form of them. So, they can exert the devastating effects from inside of the cells. The common organic acids integrated with edible films and coatings include lactate, acetate, propionate, p-amino benzoic acid, and malic acid. In a study, whey protein films incorporated with grape seeds, malic acid, and nisin were used on turkey and reduced 2.3 log CFU/g of *L. monocytogenes* and 5 log CFU/g *S. typhimurium* after 28 days of storage at 4°C. The combination of organic acids with other antimicrobial agents into coatings have been successful on meats.[43,44]

### Essential Oils and Plant Extracts

Essential oils (Eos) antiseptic properties are well known, and many research have evaluated their antimicrobial activity in the last twenty years.[45,46] Eos is defined as the product obtained from raw plants and has some advantages such as anti-cancer, anti-inflammatory, anti-diabetic, antiulcer genic, antidepressant, and antianxiety.[47,48] Eos is a concentrated and hydrophobic liquid containing volatile aroma compounds such as terpenes, terpenoids, and aliphatic chemicals. Adding essential oils directly to the edible antimicrobial films will not only decrease the number of microorganisms, but can also change their sensory properties. However, the volatile nature of essential oils can raise some problems in its application. Fortunately, some formulations of to incorporate essential oils into the coating solutions could solve these problems efficiently.[48,49]

These solutions have also enhanced the essential oils solubility in water. In a research, the oregano essential oils extracted from grapefruit seeds with concentrations of 1.5% (v/v) and 1.9% (v/v) could decrease the total viable count by 2 log CFU/g in sardine after 20 days preservation at 5°C, and the *L. monocytogenes* population by 2.4 log CFU/g after 28 days at 4°C, respectively. Also, grapefruit seed extracts added into the antimicrobial edible films have been found to prevent *E. coli* O157:H7 and *L. monocytogenes* growth from pork.[44,50]

### Bacteriocins

Bacteriocins were first recognized in 1925 and are known as ribosomal synthesized, proteinaceous toxins produced by lactic acid bacteria which control or destroy other closely related microorganisms[51,52] through numerous mechanisms such as plasmids and conjugative transposons.[53,54] Production of these components among bacterial species are widespread since it is suggested that all bacterial species can synthesize bacteriocins.[54,55]

There are several different types of bacteriocins according to their biochemical and genetic properties or the existence of disulphide or monosulphide bonds, molecular weight (2 kDa to 300 kDa), heat stability, proteolytic enzyme stability, presence or absence of post-translational modification of amino acids, and antimicrobial action.[56]

Bacteriocins could destroy microorganisms through many different ways. For example, the members of nisin can bind to lipid II on bacterial cells (the main transporter of peptidoglycan) and prevent the correct cell wall synthesis.[57] Kim et al.[58] invented an antimicrobial films containing nisin and lacticin to improve the shelf-life of fresh oysters and ground beef. Their results showed that both nisin and lacticin antimicrobial edible films slowed the growth rate of coliforms and total aerobic bacteria in oysters and ground beef.

### Proteins

The amino acid-structured antimicrobials, including enzymes, nutrient-binding proteins, and smaller antimicrobial peptides act by disrupting the structure of microbial cell membranes. A good example of protein antimicrobials is lysozyme which is active against gram-positive bacteria. Lysozyme hydrolyzes N-glycosidic chains between N-acetyl muramic acid and the fourth carbon atom of N-acetyl glucosamine in the cell wall. In one research, the effectiveness of lysozyme added to whey protein films in reducing the bacterial population of salmon slices have been approved.[44,59]

### New research about antimicrobial films and coating in meat products

Recently, researchers have been concentrated on bringing the food-grade materials into the production line to guarantee the food safety, security, and quality.[60,61]

Edible films have functional properties as preservatives in food products. Eos are one of the best examples of edible antimicrobial films, but their weak water activity restricts their applications in foods. To make water solubility property and inhibit the degradation of Eos, one of the new approaches is the creation nano-size emulsions of antimicrobial substances into the edible coatings. Some common emulsified Eos are thyme, lemongrass, and sage. Sage nano emulsion films have some properties that distinguish it from others, such as lowest whiteness, higher transparency, water vapor resistance, and flexibility.[62-64]

It has been shown that pullulan films incorporated with nano emulsified Eos have the potential to promote the safety of fresh or further-processed meat and poultry products. The mechanism of these films is based on their ability to stick to the meat and then slowly release the antimicrobial materials into the meats. In this conditions, the microorganisms do not have the opportunity to regrow.[62,65]

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Some scientists have found a number of essential oils like, oregano (Origanum vulgare), thyme (Thymus vulgaris), cinnamon (Cinnamon casia), lemongrass (Cymbopogon citratus), and clove (Eugenia caryphyllata) which have antibacterial activity against *E. coli*. Carvacrol, thyme, sage, and rosemary are more effective than the others and are GRAS.[60,62] In a study, the effect of incorporating the carvacrol and cinnamon to apple and tomato-based films on microbiology and sensory properties of wrapped cooked chicken was evaluated. The results exhibited that carvacrol with apple films have a powerful impact on *E. coli* O157:H7 in a raw chicken breast. In addition, antibacterial-carvacrol-and-cinnamon-containing edible films did not show any negative effects on sensory properties.[63,66]

Carvacrol also has an inhibitory effect on *Clostridium perfringens* during chilling of cooked beef. Chitosan-based antimicrobial films containing cinnamon aldehyde could prevent the growth of *Enterobacteriaceae* and *S. liquefaciens* on meats.[61,63,66] Likewise, Carvacrol has an effective role to destroy *Staphylococcus epidermidis* and *aureus*.[67]

The essential oils of cinnamon, oregano, and thyme have an effective function against a number of microorganisms, including *Listeria monocytogenes*, *Salmonella Typhimurium*, enterohemorrhagic *Escherichia coli* (O157:H7), *Brochothrix thermosphacta* and *Pseudomonas fluorescens*. Among these microorganisms, *P. fluorescens* have high resistance against Eos. Also, the impact of cinnamaldehyde, carvacrol, and thymol on controlling the spoilage and pathogenic bacteria in minced fish meats have been proved.[68-70]

Another new antimicrobial agent is lauric arginate. Lauric arginate is a novel antimicrobial compound, derived from lauric acid, L-arginine, and ethanol, which are all naturally occurring substances. This substance is an effective food grade antimicrobial known as Na-Lauryl-Arginine ethyl ester and also known as ethyl lauryl arginate and lauramide ethyl ester. Lauric arginate has been used against the food pathogens and spoilage microorganisms. This substance affects a various range of microorganisms, including bacteria, yeasts, and molds and can disturb the cell membrane structure. Lauric arginate has an effective role against *L. monocytogenes*, *S. enterica*, and *L. innocua* in cooked sliced turkey.[44,50,59,71]

Another new research about edible films is incorporated almond and walnut oils in whey protein isolate films. Almond oil can create a better film than walnut oil. Additionally, it improves oxygen and carbon dioxide permeability, hydrophobic properties, plasticizing effect, and decreases the hydrophilicity of the whey protein films.[72,73] Recently, researchers have tried to create a new edible and biodegradable film with phosphated cush-cush yam and cassava starches cross-linked with sodium trimetaphosphate. The amylose chains in the cassava starch have interacted with glycerol and enhanced hydrogen bonds which enable it to be more resistant against high temperatures. Phosphated starch films also have additional properties, for instance, hydrophilic characteristic, high solubility, and high crystallinity which lead to having a good quality and safety for packaging of foods.[74,75]

### Future Trends

Even though a number of antimicrobial factors exist, microorganism infections is still a major cause of deadly adverse effects for human. Currently, due to the rise of multidrug-resistant microorganisms associated with infections, developing the new antibacterial agents are more essential than in the past. For example, the use of nanoparticle-based materials as antimicrobial agents is one of them.[74] One novel approach is using the nanocomposite films.[76,77]

In this study, a nanocomposite film was prepared by mixing the solutions of gelatin with different concentrations of silver nanoparticles (AgNPs) using a solvent casting method. The creation of silver nanoparticles in the solution was approved by Surface Plasmon Resonance (SPR) band at 400–450 nm, and then measured by UV–vis absorption spectroscopy. High concentration of AgNPs was shown to decrease the water vapor permeability (WVP) and tensile strength (TS) of the gelatin films. Gelatin/AgNPs nanocomposite films have shown powerful antibacterial activity against food-borne pathogens.[78] Such coatings are expected to be utilized more in future as they are being used now.[79]

Using edible films and coatings as a protective approach can preserve food products with higher quality and safety and prolong the shelf life. The most important property of antimicrobial films besides stability, bioavailability, and functionality are compatibility with other novel protection techniques like exposure to high pressures, electric fields, ultrasound, microwave, and gamma radiation.[40,79]

## CONCLUSIONS

Antimicrobial coatings or films can be recognized as a necessity in the preservation of meats in at least last two decades. Such coatings offer several advantages such as improving the quality, increasing the shelf life, and reducing the growth rate of meat spoilage bacteria. Likewise, edible films can protect meats from outside damages, including sunlight, dust, and even air. In addition, they preserve the freshness of meats. In conclusion, with regards to the increasingly contaminated environment, high demands for biodegradable packages and foods with longer shelf life, developing the practical methods to produce antibacterial films seems to be an imperative need. Nowadays, a lot of the information about the antimicrobial edible films and coatings have been available, but unfortunately, an effective way to bring antimicrobial edible films or coatings into the production line have yet to be achieved. So Therefore, a deeper insight related to this subject is needed.

## COMPETING INTERESTS

The authors declare that they have no competing interests.

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