Antimicrobial edible films and coatings for food

Radoslav Radev[11] and *Velichka* Marinova[1]

[1]University of Economics – Varna, 77, Knyaz Boris I Blvd., 9002, Varna, Bulgaria

Abstract. Antimicrobial edible films and coatings include various antimicrobial components that preserve the quality, safety and extend the shelf life of foods. The purpose of this scientific study is to research antimicrobial edible films and coatings for food, reviewing the latest scientific research in the field in the period 2020-2025. The study shows that antimicrobial edible films and coatings have a huge potential for development in the field of food technology, help inhibit various types of microorganisms. An important modern direction in the food industry, which can be successfully used in the field of antimicrobial edible films and coatings for food, is nanotechnology. This modern trend contributes to extending the shelf life of foods, as nano-edible antimicrobial films and coatings improve their microbial resistance.

1 Introduction

In preventing microbial growth and extending the shelf life of foods and maintaining their safety, antimicrobial edible films and coatings are used, with various types of antimicrobial agents in their composition, such as essential oils, bacteriocins, enzymes, fungicides, polysaccharides, organic acids, probiotics, plant extracts and spices. Under storage conditions, some of the antimicrobial agents from the composition of antimicrobial edible films and coatings remain on the surface of the food, being released by evaporation or diffusion, depending on the degree of volatility. In the composition of antimicrobial films and coatings, the use of natural and antibacterial components that are safe is preferred, while the use of synthetic antibacterial agents raises concerns about negative effects about consumers [1].

The growth of microorganisms affects the contamination of various types of food, leading to the accumulation of food waste and/or foodborne illnesses. Foods that have a short shelf life, such as fresh fruits and vegetables, dairy products, meat are susceptible to the development of various microorganisms, which can be delayed by adding various antimicrobial agents to food packaging materials. Edible films and coatings come into direct contact with food and for this reason it is good to include antimicrobial agents in their composition. Antimicrobial agents migrate gradually from the biopolymer packaging to the food, inhibiting the growth of microorganisms, which has positive effects on shelf life and food safety [2].

[1] Corresponding author: r.radev@ue-varna.bg

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2 Antimicrobial edible films and coatings for food

Research about the use of *antimicrobial edible films and coatings* in antiquity is very scarce. The ancient process of smoking sausages is probably one of the earliest examples of antimicrobial edible films and coatings, as it causes the accumulation of antimicrobial components produced by the smoke in the casing and on the surface of the sausage. In the middle of the last century, some pectin and pectate edible films and coatings with antimicrobial agents included in their composition were patented, which laid the foundation for the development for this type of antimicrobial films and coatings. Systematic studies on the inclusion of antimicrobial components in edible films and coatings increased in the 1980s and 1990s. Nowadays, antimicrobial edible films and coatings are a rapidly developing field that plays an important role in improving the safety and preservation of food quality, while preserving the health of consumers in accordance with environmental requirements [3].

In search of a reliable option to extend the shelf life and maintain the safety of various types of food products, *antimicrobial edible films and coatings* are used. Different types of antimicrobial components are included in the composition of different types of edible films and coatings and for this reason they are called *antimicrobial edible films and coatings*. In recent years, there has been an increased interest in the use of natural antimicrobial components as a substitute for synthetic antimicrobial components that have potential toxic effects. Natural antimicrobial compounds are obtained from various plants, animals and microorganisms, and subsequently the influence of their antimicrobial properties against various types of pathogenic microorganisms that cause spoilage of various types of foods has been studied. Antimicrobial edible films and coatings improve food safety and shelf life by inhibiting the growth of microorganisms (including pathogenic microorganisms), reducing or delaying the microbiological causes of food spoilage. When selecting an antimicrobial agent in the composition of antimicrobial edible films and coatings, it is necessary to consider their bactericidal and fungicidal capacity, stability at temperature and pH, activity at low concentrations, impermeability to color, taste and toxicity. The use of antimicrobial edible films and coatings on chicken meat with the inclusion of essential oils, bacteriocins and plant extracts helps to *extend the shelf life of chicken meat up to 12 days by controlling microbial growth* [4].

The possibilities of preventing microbial growth from *antibacterial edible films with tragacanth gum, carrageenan and clove essential oil* in their composition were investigated. The influence of different concentrations (10%, 20% and 30 w/w%) of clove essential oil on the properties of the antimicrobial edible film - physical properties, optical properties, mechanical, antimicrobial properties, biodegradable properties - was studied. The results obtained show that the addition of clove essential oil has a positive effect on the elongation of the film, reducing the tensile strength and elasticity. In addition, the study found an interaction between tragacanth gum/carrageenan and clove essential oil, which is expressed in the fact that the presence of clove essential oil reduces the water vapor permeability and moisture content of the antimicrobial edible films, increasing their antimicrobial and antioxidant properties, which lead to positive effects. The study shows that the antimicrobial edible film, which contains 30% clove essential oil, shows strong inhibitory properties and effect against *Bacillus and Escherichia coli*, and the addition of tragacanth gum/carrageenan improves the properties of the film, making it suitable for food packaging [5].

In another scientific work, *gelatin antimicrobial edible films with garlic peel extract and aloe vera gel* were proposed for use in food packaging. Nine different concentrations of edible gelatin antimicrobial films with garlic peel and aloe vera gel showed high total

phenolic content, total flavonoids and antioxidant activity. Edible antimicrobial films with 3% gelatin with extracts in a ratio of 1:1 (garlic peel:aloe vera gel) had the highest results. Gelatin antimicrobial edible films enriched with garlic peel and aloe vera gel in their composition slowed down the growth of *S. aureus* and *E. coli*. The study found that the addition of the indicated extracts did not significantly affect the barrier and mechanical properties - water vapor permeability and oxygen permeability coefficient. The inclusion of garlic peel and aloe vera gel in the composition of gelatin antimicrobial films can be proposed for application on meat and poultry products, which will lead to an extension of the shelf life of foods by slowing microbial growth [6].

In studies related to antimicrobial edible films and coatings, it was found that freshly cut pears retained their freshness when treated with an antimicrobial edible starch film containing *Adiantum capillus-veneris extract*; a study found that higher concentrations of essential oil in the composition of the edible antimicrobial film increased its antibacterial effectiveness; under certain conditions - low pH, high temperature, low oxygen concentrations, essential oils have strong antibacterial effects [1].

A study investigated the potential of *an antimicrobial edible film of soy protein isolate, with sage essential oil* in its composition, to *extend the shelf life of fresh Kachar cheese*. For this reason, three different types of edible films were created, which have different compositions - the first group was coated with a film containing soy protein isolate and 3% (w/v) glycerol, the second group and the third group were coated with films containing 1% and 2% sage essential oil (*Salvia officinalis L*), respectively. Control cheese samples were not coated with an antimicrobial edible film. The study found the main active ingredients of sage essential oil as α-thujone (39.46%), d-camphor (14.67%) and 1,8-cineole (eucalyptol) (9.79%). Sage essential oil, which is included in the composition of the antimicrobial edible films, significantly affected the results when compared to the control sample of fresh Kachar cheese. In the studied samples of *fresh Kachar cheese*, *Escherichia coli O157:H7*, *Staphylococcus aureus*, *Listeria monocytogenes* and *Penicillium spp.* were inoculated. The antimicrobial effect of the antimicrobial edible films was studied for 30 days, with higher concentrations of sage essential oil leading to an increase in their antimicrobial activity, reducing *E. coli O157:H7* by approximately 3 log, *S. aureus* by 3.5 log, *L. monocytogenes* by 4.25 log and *Penicillium spp.* by 3.5 log units. The results prove that the successful development and application of *antimicrobial edible films from soy protein isolate and sage essential oil for fresh Kachar cheese* was achieved [7].

Antimicrobial edible films and coatings are extremely important as they preserve the quality and safety of various types of food products. In addition, antimicrobial edible films and coatings applied to foods extend their shelf life by using various antimicrobial components that inhibit various types of microorganisms. The antimicrobial components included in the composition of antimicrobial edible films and coatings are important, and they must be carefully selected to have high efficiency in their interaction with the various types of microorganisms that are characteristic of the specific food product. The study of the scientific literature on antimicrobial edible films and coatings for various types of food will remain incomplete if we do not invert attention to the innovative technologies in the field related to the creation of nano-edible antimicrobial films and coatings, which are an important innovative direction.

3 Nano-edible antimicrobial films and coatings for food

Nanotechnologies are used in various fields, and the food industry is increasingly relying on them.

According to authors [8] at the current stage of industrial development, the demand for healthy foods and those without chemicals makes nanotechnology edible coating films a

preferred and reliable food packaging system. Nanotechnology is emerging as a promising approach in the food industry thanks to its improved mechanical characteristics, high durability, and antimicrobial activity that extends the shelf life of food. Depending on the functionality of nanoparticles and in the context of their use in *active packaging, enhanced packaging, smart packaging and bio-based packaging*, nanotechnology is part of the new trends in food packaging [8].

A serious challenge in the food industry is bacterial contamination, which affects quality, safety and consumer health. Nanocoating is a good solution to replace plastic packaging and the environmental problems associated with it. One form of nanocoating is edible, formed directly on the surface of food and can be consumed as an integral part of the food product. Thin edible nanocoatings are created on the outer surface of fresh fruits and vegetables, raw meat, cheese, ready-to-eat foods, and baked goods. Antibacterial nanocoatings prevent the growth of pathogenic bacteria and food spoilage, extending the shelf life of food. The authors conclude that the main targets of antibacterial coatings are strains of *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Escherichia coli*, *coagulase-negative staphylococci*, and *Enterococcus spp.* [9].

Applications such as effective antimicrobial action, providing barrier protection, reducing spore formation, extending shelf life, and preventing food contamination are the main objectives of ***functionalized nanomaterials*** [10]. In their scientific review, the authors summarize the types of edible coating materials for food storage studied over the past few years and the several modifications of edible functional additives developed by integrating *nanopolymers, nanofibers, lipid nanoparticles, nanoemulsions and polymer nanocomposites* to form a coating [11].

The production of functionalized nanomaterials involves the integration of nanomaterials (certain classes of nanoparticles, metals, polymers, their oxides, organic-inorganic hybrids and clay nanoparticles incorporated into a suitable matrix or substrate) onto various working surfaces, which enhances their bactericidal effectiveness. Depending on the composition of the nanomaterial, functionalized nanomaterials for antimicrobial food packaging are classified into the following ***categories***:

- Core-shell nanomaterials;
- Metallic nanomaterials;
- Metal-oxide nanomaterials;
- Organic-inorganic hybrid nanomaterials;
- Clay nanomaterials.

These nanomaterials exhibit exceptional antimicrobial properties within the so-called ***bio-nanocomposites***, which are gaining increasing popularity [10]. The main advantages of using bio-nanocomposites for food packaging are that they protect food, extend shelf life, and are environmentally friendly as they reduce the consumption of packaging plastics. Bio-nanocomposites are hybrid forms of nanostructured materials with better control of gas, thermal, and mechanical barrier properties [12].

Summarizing the latest trends in the use of nano-edible coatings to extend the shelf life of food and horticulture, and focusing on technological aspects such as coating materials, application methods and their impact on quality and nutritional value, as well as functional additives in them, nano-edible coatings are ***systematized*** by the authors [11] as:

- Nano-edible coatings based on starch;
- Nano-edible coatings based on pectin;
- Nano-edible coatings based on essential oils;
- Nano-edible coatings based on copper;
- Nano-edible coatings based on chitosan.

Nanoparticles (NPs) with high length-to-width ratios are particularly interesting due to their high specific surface area, antimicrobial properties, and reinforcing effect in the matrix

[13]. The use of nanoparticles in the composition of coatings with antimicrobial properties determines the leading position of organic and inorganic NPs, in particular *silver NPs, titanium oxide nanoparticles, and zinc oxide nanoparticles*, which have a broad antimicrobial spectrum against Gram-positive and Gram-negative bacteria. These nanomaterials are synthesized from various bio-based resources and mixed with biopolymer matrices for edible coatings to prevent food spoilage, preserve quality and extend shelf life [8]. Other nanoparticles, such as titanium dioxide, iron, copper, and cerium oxide, are used in various areas of the food sector. Edible coatings with added nanoparticles in their composition increase antimicrobial activity [14].

Nanoparticles can be obtained by various ***methods***: *mechanical attrition* - nanostructures are produced by mass assembly; *electrodeposition* - these layers are homogeneous and mechanically durable; *chemical precipitation* - size control is achieved by the technique of retained precipitation [Wahab et al, 2021]. Common procedures for preparing films for coating food products with NPs include dissolving or dispersing the coating materials, making an emulsion, and evaporating the solvent [8].

Due to the size of the particles, there are various possibilities for incorporating nanocoatings into polymer matrices suitable for use in the food industry. When interacting with the coating matrix, different types of systems have different contributions. The ***nanosystems*** themselves are usually mixed into protein or polysaccharide matrices, known as ***"nanocomposites,"*** which can be defined as a mixture of two or more materials forming a mixture that helps improve the characteristics of a component in which at least one of them is on a nanometric scale. Functionalizing agents for modifying the surface of various nanomaterials are also classified.

Nanoemulsions have significant potential as delivery channels for active ingredients in edible coatings with antimicrobial activity. The particle size of nanoemulsions varies from 50 nm to 500 nm. They are divided into two groups depending on the phases involved: water/oil (w/o) and oil/water (o/w).

Polymer nanoparticles in edible coatings - essential oils are several other compounds with higher quality for use in polymer nanoparticles, accompanied by use in edible coatings. Although there are many formulated polymers for the preparation of polymer nanoparticles, special attention is paid to the formulation of chitosan nanoparticles in food applications. It is biodegradable, non-toxic, biocompatible, with better mechanical properties and film-forming ability, as well as fungicidal and antimicrobial properties and selective gas permeability.

Solid lipid nanoparticles (SLNs) are a potential method for delivering bioactive compounds in food products and as a component of edible coatings due to their significant stability and high load capacity. SLNs include lipophilic antioxidants, nutraceuticals, and antimicrobial agents with active delivery mechanisms, which increases their safety, solubility in aqueous environments and bioavailability.

Inorganic nanocomposites in edible coatings - inorganic compounds are vital for the production of edible coatings, in which certain components require a small proportion.

Nanotubes and nanofibers - the electrospinning method allows the production of nanofibers that can be functionalized with various active substances that may have antimicrobial effects. These nanosystems are often integrated into polymer matrices (polysaccharides and proteins) that can be functionalized with various essential oils and natural products [14].

At the current stage of development, growing consumer demand for nutritious, environmentally friendly, and economical food products is leading to the development of new and more efficient technologies for the production of edible films. Therefore, nanoscience and nanotechnology are emerging as a promising opportunity to meet consumer demand [8].

Modern technologies rely on innovative methods and practices to achieve sustainable production and consumption. Nanotechnologies are a promising field that is finding its place in the food industry. Together with the gaining popularity and increasing application of edible coatings and films, they can provide the right solution to the main causes of food spoilage, extending their shelf life by improving their microbial resistance. The application of nanotechnologies in the food industry opens up opportunities for extending the shelf life of various food products, especially when their spoilage is determined by the activity of microorganisms – bacteria and moulds. The possibility of replacing standard packaging and obtaining active antimicrobial agents while preserving food quality is a key factor in the use of nanoscale particles in edible coatings.

Nano-edible antimicrobial coatings can include various components, which are presented in a variety of combinations. Interest in them is also driven by the demand for environmentally acceptable and economically viable solutions in the food industry. However, nano-edible coatings are still in the process of development and experimental application. Achieving sustainable application should meet all criteria and requirements ensuring quality, safety, and cost-effectiveness. This means that more research is needed to demonstrate their effectiveness compared to conventional materials with such properties in the food industry.

4 Conclusions

Antimicrobial edible films and coatings have a huge potential for development in the field of food technology, which is important for maintaining the quality, safety and extending the shelf life of food products produced by the food industry. The antimicrobial components incorporated into the composition of edible films and coatings help inhibit various types of microorganisms, which makes them particularly effective according to the specifics of a food product.

An important modern direction in the food industry, which can be successfully used in the field of antimicrobial edible films and coatings for food, is nanotechnology. Nano-edible antimicrobial films and coatings also contribute to extending the shelf life of foods by improving their microbial resistance. This provides the opportunity to replace conventional packaging with nano-edible antimicrobial films and coatings, which preserves the quality of food, and can also provide a prerequisite for exploring the possibilities of economic and environmental efficiency.

Future research in the field of antimicrobial edible films and coatings may be directed towards the search for optimal concentrations of the composition of antimicrobial edible films and coatings (including in the field of nanotechnology) and precise selection of an antimicrobial agent that is in accordance with the specificity of the studied foods and the microorganisms contained in these foods.

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