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Biodegradable packaging materials for food products

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Overcoming the problem of microbial recontamination of various ready-to-eat food products can be achieved through proper packaging. The paper analyzes current trends in the development of biodegradable edible coatings for food products. Strategies for improving mechanical and barrier properties by creating nanocomposites and blends with other biopolymers are considered. Special attention is paid to the concept of active packaging using essential oils and natural antioxidants, which helps to extend the shelf life and improve the quality of food products, as well as to meet the growing consumer demand for more natural and environmentally friendly products. The results of the analysis confirm the effectiveness of coatings in extending the shelf life of products and ensuring their microbiological safety. The review presents the current state of the art in the application of antimicrobial biodegradable films in food packaging, and also highlights current research on the implementation of nanotechnologies for the development of new biodegradable packaging systems. The practical significance of the work lies in the fact that the use of the developed compositions allows the shelf life of perishable products (meat, fish, dairy, fruit and berry products) to be extended for a significant period of time, depending on the composition of the coating and storage conditions, which is of great importance for the sale of goods and logistics chains.

Keywords: edible coating; active packaging; essential oils; microorganisms; antimicrobial films.

Introduction

The transition from traditional plastics to edible films and coatings has become a necessity for the sustainable development of the food industry. Food packaging is a critical element for ensuring the quality, safety, and shelf life extension of food products, as it acts as a barrier, protecting against physical, chemical, and microbial hazards, as well as moisture, light, and oxygen. Nanocomposite biopolymer packaging materials are a promising, environmentally friendly alternative to traditional plastics. Due to the introduction of nanofillers, these materials demonstrate improved mechanical and thermal stability (Palamarchuk et al., 2024a, 2024b), excellent barrier properties against oxygen, moisture, and lipids, and antimicrobial properties, which allows a significant extension of the shelf life of food products (Brovenko et al., 2025). The introduction of antimicrobial agents into biopolymer films solves a critical dilemma: how to extend the shelf life of products without resorting to aggressive chemical treatment of the food itself. The use of nanoencapsulation and bio-nanocomposites allows the release rate of active substances to be controlled, which makes the protection "smart" and long-lasting. Key aspects of the analysis of biopolymers are the natural antimicrobial agents, the mechanical properties of the films and the ecological cycle of biopolymers, thanks to which such packaging is completely biodegradable. Traditional plastic made from petroleum products can take centuries to decompose, which leads to the accumulation of microplastics in ecosystems and oceans (Zhong et al., 2020). It is impossible to completely replace traditional petroleum-based plastic with biodegradable plastics, but the use of these biodegradable active packaging materials is a practical solution, especially for food packaging (Ataei et al., 2021). Researchers have focused their research on various methods for developing safe and reliable biodegradable packaging, and biodegradable food packaging has attracted significant interest from the food industry due to its renewable and environmentally friendly properties (Zhong et al., 2019; Haider et al., 2019; Rechun & Peredriy, 2021).

Biopolymers (such as starch, chitosan, gelatin, alginate or whey proteins) have unique properties: they decompose in nature, solving the problem of plastic pollution; the film can be consumed together with the product, for example on sausage casings or fruit coatings; the structure of biopolymers allows for easy retention of active ingredient molecules and their gradual release (Sasikanth et al., 2024; Dutta & Sit, 2024; Gheorghita et al., 2021). The development and production of environmentally friendly antimicrobial packaging materials are of great importance, although the differences between biodegradable behavior and antimicrobial activity should be carefully considered, as pointed out by scientists Ates & Kuz (2020); Zhang et al. (2020). Therefore, it is important to choose the right antimicrobial agent that is specific to food products and the appropriate packaging, considering its minimum inhibitory concentration against microorganisms.

Edible films from food waste

Replacing synthetic films with edible or biodegradable coatings is desirable from an environmental point of view. A promising trend in this area is the use of nanoemulsions based on polysaccharides or essential oils, with the inclusion of bioactive ingredients or encapsulated nanocoatings, which can also inhibit the growth of pathogenic microorganisms. The use of polysaccharides for the preparation of edible films and coatings is justified not only by the possibility of reducing the consumption of packaging from synthetic polymer materials, but also by the fact that the production of some natural polymers can be carried out using waste generated during the processing of food raw materials. Natural edible polysaccharide coatings provide a promising approach to improving the quality and extending the shelf life of fruits and vegetables (Kocira et al., 2021).

Studies conducted by Panahirad et al. (2020) showed the positive effects of edible coatings based on carboxymethylcellulose and pectin, both individually and in combination with each other, on plum fruits during storage at reduced temperature. The coatings particularly improved the content of vitamin C, total phenolics, anthocyanins and flavonoids, as well as the activity of POD enzymes and reduced the activity of PPO and PG enzymes. Carboxymethylcellulose at 1% and pectin at 1.5% concentration showed the best results. In addition, the researchers found that 0.5% pectin combined with 1.5% carboxymethylcellulose is a good combination formula for preserving the nutritional value of plums after harvest. Therefore, the use of carboxymethylcellulose and pectin individually or in combination can be considered as a favorable and safe coating approach to extending and improving the quality characteristics of plum fruits after harvest.

The article by Zheplinska et al. (2025a) shows the possibility of using apple pomace pectin for the production of edible film for food protection, antimicrobial biofilms, nanoparticles that extend the shelf life of food products. Pectin-based food film from apple waste protects the product from mechanical damage, chemical and microbiological action.

Agro-industrial wastes, which are formed from cassava, deserve to be studied as alternative sources of starch and the creation of food coatings based on it (Zheplinska et al., 2025b). It has been established that edible cassava coating increases the shelf life of food products by reducing the respiration rate (Garcia et al., 2010).

The use of chitosan allows the creation of packaging that not only protects the product, but also actively inhibits pathogenic microflora (*Listeria monocytogenes, E. coli*) (Díaz-Montes & Castro-Muñoz, 2021). A microbial biopolymer called pullulan, which is traditionally used as a food additive, is of interest for use in food packaging due to its exceptional film-forming ability, biodegradability and non-toxicity (Bibek et al., 2026). Encapsulation of bioactive substances (eg essential oils or antioxidants) in the pullulan structure prevents their rapid evaporation. The substances are released gradually, which extends the shelf life of the product. For products rich in protein (meat, fish, seafood), the release of volatile nitrogen compounds (TVB-N) during spoilage is characteristic. Integrating natural pigments (such as anthocyanins from berries or cabbage) into the pullulan film allows the packaging to change color depending on the pH level, which is a direct indicator of freshness.

The use of essential oils in biodegradable materials

The use of natural plant raw materials in active packaging inhibits microorganisms, preventing spoilage and extending the shelf life of products. This ensures quality and safety during logistics, and the availability of raw materials allows domestic manufacturers to implement these innovations. This is the conclusion made by Lebedynets & Lebedynets (2020), who emphasized the relevance of using plant extracts and essential oils, which are characterized by high bactericidal properties and safety. As antimicrobial additives, they recommend using essential oils and extracts of spicy-aromatic plants, in particular cloves, cinnamon, turmeric, nutmeg, oregano, rosemary and garlic.

Table 1 presents the results of the effect of essential oil from some spicy-aromatic substances as a food film using chitosan on the effect in food products.

Table 1
Effect of essential oils in chitosan films

No.	Essential oil	Main active ingredient	Foodstuff	Effect of use
1	Cinnamon	cinnamaldehyde	bakery products, fruits	powerful effect against mold fungi
2	Thyme	thymol	fresh meat, poultry	effective against *salmonella* and *staphylococcus aureus*
3	Oregano	carvacrol	cheeses and delicacies	antibacterial effect
4	Rosemary	carnosol, cineol	fatty fish and meat	powerful antioxidant; prevents fat oxidation
5	Lemon/tea tree	limonene/terpinene	vegetables and berries	suppresses fruit respiration, preserves their firmness and color

As can be seen from Table 1, the choice of oil depends on the product, since each of them has a different spectrum of action on microorganisms and the organoleptic characteristics of all types of oils also differ in smell and taste. The addition of essential oils transforms the passive film into an active antimicrobial system. The components of thyme and oregano oils (thymol, carvacrol) destabilize the membranes of bacteria, and chitosan enhances this effect by physically limiting the access of oxygen. The oils increase the film's resistance to water, which is important for wet products. It is on this action that cinnamon oil works, effectively inhibiting the growth of mold, which causes food spoilage. Carnosol, contained in rosemary oil, protects meat (pork, beef) and fish from lipid oxidation, which significantly extends the shelf life of these foods. Lemon and tea tree essential oils have powerful antimicrobial, antibacterial and antifungal properties, making them potential natural preservatives, so they can be used to protect foods from spoilage.

Essential oils often act as plasticizers, making the film less brittle. The most effective combinations are: chitosan and cinnamon oil, which gives the best protection against mold for baked goods, or chitosan and thyme/oregano oil (effective in protecting meat from against *E. coli* and *Salmonella*).

Instead of chemical stabilizers, solid nanoparticles (e.g., nanocellulose) are used to mix oil with chitosan, which represents the modern concept of "Pickering Emulsions" (Guzmán, 2024).

The oil is released from the product surface very slowly, which extends the protective effect of the film from 2–3 days to 2 weeks (Abreu et al., 2011). Without a plasticizer, the cling film will be like a dry leaf, so it is best to use glycerin or polyethylene glycol at a concentration of 25–30% by weight of chitosan.

Active packaging

There is a growing demand for environmentally friendly packaging for food storage, which is due to the great potential of antimicrobial packaging to extend shelf life and improve product safety. Traditional packaging materials contribute to environmental pollution, while microbial contamination continues to threaten food safety (Balprylypko et al., 2022). A review by Nor et al. (2025) investigated antimicrobial packaging systems that combine active agents with biodegradable polymers to combat foodborne pathogens and environmental contamination. Antimicrobial agents consist of natural extracts, organic acids, enzymes, bacteriocins and nanomaterials, due to which they inhibit the growth of microorganisms and modify the permeability of cell membranes. Coating, extrusion and electroforming optimize the antimicrobial functionality of such systems. Biodegradable polymers in these packaging systems decompose naturally after use, reducing the amount of harmful waste. Smart packaging, integrated with indicators and pH or temperature sensors, allows real-time monitoring of the condition of food products, providing consumers with actionable information about the entire supply chain, due to which manufacturers can more quickly identify weak points in logistics, where goods are most likely to overheat or be damaged.

As noted by Yin et al. (2023), active packaging is designed to improve the shelf life of packaged foods by incorporating antimicrobials or antioxidants such as essential oils. Smart packaging is designned to provide real-time information about the quality, freshness, or safety of packaged foods by incorporating indicators into the film that respond to changes in storage conditions, gas levels, pH.

Natural antimicrobial agents (essential oils from spices, bioactive compounds derived from vegetables and fruits, compounds of animal and microbial origin with antimicrobial properties) can be used in edible film as a replacement for synthetic compounds, maintaining quality and human health (Punia Bangar et al., 2021).

The type of active ingredients and materials used in the production of edible film are among the most important considerations for choosing an appropriate evaluation method. The results of researchers Abdollahzadeh et al. (2021) showed that disk and well diffusion assays followed by viable cell counting methods are the most common methods for assessing the antimicrobial activity of edible films.

Lactoperoxidase, which is a natural protein of milk, can be used as part of packaging material, especially edible and coating, to preserve its antimicrobial properties to extend the shelf life of food products and ensure food safety (Yousefi et al., 2022).

Pea protein is a promising alternative to animal protein, and interest in its application in the food industry is rapidly growing. In a study by Cheng & Cui (2021), pea protein isolates were used to form edible protein-based films, and it was found that ultrasound significantly improved the film transparency, increased its tensile strength, and reduced the moisture content and water vapor permeability of the film.

Active edible packaging is not only promising for the near future, with a number of advantages, but many countries are tightening their bans on single-use plastics. Active packaging helps to extend the shelf life and sometimes improve the quality of food products, as well as meet the growing consumer demand for more natural and environmentally friendly products. However, before they can be adopted by the industry on a larger scale and thus reduce the use of modern traditional packaging, some limitations still need to be overcome. This requires further research into natural active compounds from agricultural waste and their compatibility with biopolymers, as well as research into solutions to improve the barrier and mechanical properties of active packaging (Barbosa et al., 2021).

A comparative characteristic of traditional and active packaging of food products is presented in Table 2, which lists the advantages of active packaging over traditional packaging.

Table 2
Distinguishing factors of traditional and active packaging

Properties	Packaging	
	traditional	active
Interaction	inert to the product	controlled release of agents
Environmental friendliness	plastic accumulation	biodegradability of packaging
Function	barrier (light, moisture, oxygen)	protection and active suppression of microbes
Packaging expiration date	limited	prolonged

Consumers undoubtedly support sustainable packaging, but in real-world purchasing situations, willingness to buy is often much lower because they have to pay more for such packaging (Cruz et al., 2022).

Antimicrobial films based on natural biopolymers

Antimicrobial starch films with a combination of silver nanoparticles (AgNPs) and zinc oxide nanoparticles (ZnONPs) were prepared by Zhai et al. (2022) by blow molding. The incorporation of nanoparticles improved the mechanical and barrier properties of the film. UV-visible spectroscopy showed that the SP-ZnO(1) film had the highest UV absorption. The inhibitory effect of the nanocomposite films against Gram-positive (*S. aureus*) and Gram-negative (*E. coli*) bacteria was observed. The antimicrobial efficacy of such films reached more than 95% within 3 hours of contact. The combination of AgNPs and ZnONPs in starch blends showed a synergistic effect in improving the material properties and antimicrobial efficacy of the films. Studies on peach and nectarine packaging showed that antimicrobial films prevent spoilage of fresh produce and extend the shelf life.

Nanotechnology and its applications in advanced food packaging systems (nanoclay, carbon nanotubes), active food packaging (silver nanoparticles (Ag NPs), zinc oxide nanoparticles (ZnO NPs)), smart food packaging and biodegradable packaging (titanium dioxide nanoparticles (e.g. TiO_2 NPs)) help to overcome the problems associated with traditional packaging materials. Strong regulatory frameworks and safety standards are needed to ensure the appropriate use of nanocomposites. It is also necessary to investigate how to realize the economic and technical requirements for large-scale implementation of nanocomposite technologies (Zhou et al., 2024).

Ahmadi et al. (2024) evaluated the idea of using cellulose nanocrystals to control the migration of silver nanoparticles (AgNPs) from polycaprolactone-based films to tilapia fish. This resulted in a reduction in microbial activity in the samples compared to the control sample. Therefore, the idea of using cellulose nanocrystals together with antibacterial metal-based nanoparticles can control the rate of ion migration. Zhang et al. (2024) created edible whey protein films incorporating antimicrobial peptides derived from milk and compared their mechanical properties for potential use in cheese packaging with films containing nisin, which shows significant antimicrobial activity against Gram-positive bacteria. It was found that the peptides derived from milk have great potential for use as food preservatives. Antimicrobial peptides in whey protein films increased film opacity and water vapor properties, but reduced tensile strength and elongation at break. They demonstrated significant inhibitory activity against microorganisms (*E. coli* and *B. subtilis*) in cheese due to surface contamination during storage and demonstrated themselves as active packaging materials.

A chitosan composite film (Ag-HAP@CS) with functionalized silver and hydroxyapatite was developed by incorporating Ag-HAP into the chitosan matrix to address the problem of microbial spoilage during seafood preservation. The results of the research demonstrated the potential of such films as multifunctional packaging materials for extending the shelf life of seafood (Sun et al., 2025).

A composite film based on bovine serum albumin with the addition of copper ions has pronounced enzymatic activity, antibacterial properties, thermal stability and biocompatibility and shows excellent efficacy in slowing down enzymatic browning and inhibiting microbial attack of fresh-cut apples and figs, even when stored at room temperature. In addition, this new composite film is inexpensive and easy to synthesize for large-scale use (Zhang et al., 2024).

A transparent film with antibacterial properties and excellent tensile strength using keratin extracted from chicken feather waste combined with citric acid-modified cellulose nanocrystals demonstrated an elongation at break of 209%, highlighting its significant potential for food packaging applications and addressing the brittleness problem associated with keratin-based films. The research paper by Zhang et al. (2024) shows the great potential of keratin, which is obtained from biomass waste, in creating functional films with antibacterial properties, which offers great prospects for application in food packaging.

The inhibitory effect and germicidal activity of oregano essential oil on *V. vulnificus* in oysters at 25 °C were investigated. A 48.2% reduction in bacterial count was found after treatment with oregano essential oil for 10 hours. Therefore, the cost-effectiveness and safety of this oil allow its use for controlling *V. vulnificus* contamination in oysters and other seafood (Luo et al., 2022).

Using edible coatings for food products

The use of active biopolymer packaging systems, in combination with various bioactive agents, has significant potential for improving the quality and safety of food products, as well as for possibly increasing their shelf life.

All food products are distinguished by their excellent nutritional quality, but are prone to rapid spoilage due to their high moisture content. Such products are vulnerable to microbiological contamination, and therefore spoilage, the development of foreign flavors, enzymatic darkening and texture disruption. To overcome the problems of microbiological contamination and spoilage of fruit and vegetable products, fresh and dried meat products, fish and seafood, dairy products, the use of environmentally friendly biopolymer packaging materials is of current relevance, being able to increase their shelf life (Valdés et al., 2017; Chen et al., 2019).

Table 3 shows the use of appropriate edible coatings for raw materials and finished food products for fruit and berry raw materials, vegetables, meat, fish and dairy products with the corresponding effect on reducing and inhibiting microorganisms that lead to spoilage of finished products.

Humans obtain protein from meat, which includes both fresh and cured meat products. However, it is susceptible to rapid spoilage due to microbiological contamination, particularly by pathogens such as *Listeria* monocytogenes, which poses a major challenge for the finished product packaging sector. In meat, protein quality is of great nutritional importance and can be achieved through proper packaging (Melnyk et al., 2024). Among the various options is the use of environmentally friendly biopolymer packaging materials that ensure good quality and safety of meat products.

Table 3
The effect of using edible coatings on food products

Raw/ finished product	Edible coating	Effect of use	Source
		Fruit and berry raw materials and vegetables	
Grapes, apples, melons	Hydroxypropyl methylcellulose and chitosan activated with bergamot essential oil	Maximum control over respiration rate with minimal weight loss during post-harvest cold storage	Sánchez-González et al. (2011); Salvia - Trujillo et al. (2015); Raybaudi-Massiliaet al. (2008)
Avocado	Candelilla wax, which contains ellagic acid	Improving microbiological quality and shelf life	Ochoa Reyes et al. (2011)
Canned peaches	Polylactic acid with angelica essential oil	Improved permeability for water vapor and gas	Jiang et al. (2023)
Guava	Chitosan and alginate-based coating with pomegranate peel extract	Antifungal activity against different strains *of Colletotrichum gloeosporioides*	Nair et al. (2017)
Oranges	Chitosan and locust bean gum coating with pomegranate peel extract	Inhibition of growth and reproduction *of Penicillium digitatum*	Kharchoufi et al. (2018)
Raspberry, strawberry	Green tea and oleic acid extracts	Antiviral activity against human enteric viruses such as hepatitis A virus (HAV) and human noroviruses (NOV)	Falco et al. (2018)
Broccoli	Extracts of tea tree, rosemary, pomegranate, resveratrol and propolis	Slowing the growth of *E. coli* and *Listeria monocytogenes*	Alvarez et al. (2017)
Freshly cut apples	Polysaccharide-based coatings (alginate, pectin and gellan gum) gum) with the inclusion of apple fibers and inulin	Reduction of the number of mesophilic and psychrophilic microorganisms throughout the entire storage period	Moreira et al. (2025)
Melon	Zein with essential amino acids (eugenol, thymol and carvacrol)	Antimicrobial activity against *Listeria innocua* and *E. coli*	Boyacı et al. (2019)
Bananas	Quaternized chitosan films with carboxymethylcellulose	Slow fruit degradation	Hu et al. (2016)
Tomatoes, cherries, blueberries	Chitosan and quinoa protein	Antimicrobial activity against *Listeria innocua, Sal-monella typhimurium and Staphylococcus aureus;* improved water-repellent properties of the film	Medina et al. (2019)
		Meat products	
Chilled beef	Whey protein with oregano essential oil	Antimicrobial activity	Zinoviadouet al. (2009)
Fresh chicken breast	κ-carrageenan with a combination of ethylenediaminetetraacetic acid and ovotransferrin	Inhibitory effect against *E. coli* and reduction of total aerobic bacteria	Seol et al. (2009)
Turkey products	Starch, alginate, xanthan gum, pectin and κ-carrageenan, and activated with various bioactive compounds (nisin, sodium lactate, Novagard CB1, potassium sorbate, sodium diacetate)	Preventing contamination caused by *Listeria monocytogenes*	Juck, Neetoo & Chen (2010); Loiko et al. (2024); Zheplinska et al. (2024b)
Preserving thin slices of raw meat	Cellulose containing lysozyme or a combination of lysozyme and lactoferrin	Reduction in total bacteria count	Barbioli et al. (2012)
Chicken fillet	Gelatin integrated with chitosan nanofibers and ZnO nanoparticles	Reduction in the growth of *Staphylococcus aureus* and *Escherichia coli*	Amjadi et al. (2019)
Chicken breast	Ginger essential oil nanoemulsions	Improving shelf life	Noori et al. (2018)
Pork chops	Chitosan with ethylene glucose	Reducing chemical and microbial spoilage of the product during storage	Zhang et al. (2019)
Poultry	Gelatin nanofibrous matrix with thyme nanoparticles	Protection from *Campylobacter jejuni* contamination	Lin et al. (2018)
Sausage	Chitosan with green tea extract	Inhibition of microbial growth and improvement of antimicrobial and antioxidant characteristics of the film	Siripatrawan & Harte (2010); Nikolaenko (2021); Antoniv et al. (2025)
		Fish and seafood	
Cold smoked salmon fillets and slices	Alginate coatings embedded with sodium diacetate and sodium lactate	Growth retardation and reduction of *L. monocytogenes*	Neetoo et al. (2010)
Cold smoked sardines	Oregano/rosemary based gelatin films with chitosan	Reducing the rate of lipid oxidation in sardines	Gómez-Estaca et al. (2007)
Trout fillet	Carrageenan films with the addition of citric acid ether	Improving the shelf life of fillets	Volpe et al. (2014)
Fish megrim	Polylactic acid containing sorbic acid and freeze-dried seaweed (*Ficus spiralis)*	Preserving the sensory quality of fish	García-Soto et al. (2015)
Hake and sole fillets	Gelatin films supplemented with chitosan esters, pepper or cloves	Reduced microbial growth *L. monocytogenes, Aeromonas hydrophila* and *Staphylococcus aureus*	Shakila et al. (2015)
Cold smoked salmon	Cellulose films containing potassium sorbate, sodium benzoate and nisin	A significant decrease in the number of *L. monocytogenes*	Neetoo & Mahomoodally (2014)
Fresh silver carp fillet	Sodium alginate coating enriched with horse mint essential oil	Inhibition of microbial growth and contamination during 12 days of refrigerated storage	Heydari et al. (2015)
Rainbow	Fish gelatin enriched with ethylene glycol oregano	Reduction of populations of psychotropic bacteria	Hosseini et al. (2016)
Chopped trout fillet	Chitosan-based gelatin films containing *Ziziphora clinopodioides* essential oil and grape seed extract	Reduction in the total number of viable, number of enterobacteria, number of psychrotrophic bacteria, reduction in total volatile nitrogen and peroxide content during the 11-day storage period	Kakaei & Shahbazi (2016)
		Dairy products	
Cheese	Sodium caseinate films with added nisin	Strong antimicrobial activity against *L. monocytogenes*	Cao-Hoang et al. (2010)
Fresh cheddar cheese	Chitosan coatings embedded in nisin and silica liposomes	Growth inhibition *of L. monocytogenes*	Cui et al. (2016)
Low-fat sliced cheese	Nanoemulsion-based packaging material containing oregano essential oil with sodium alginate, mandarin fibers and Tween-80	Reduction of *S. aureus*, limiting the growth of psychrophilic bacteria, yeasts and molds	Artiga-Artigas et al. (2017)

Raw/ finished product	Edible coating	Effect of use	Source
Skimmed milk	Polylactic acid with nisin	Preventing the growth and contamination of *L. monocytogenes*	Jin (2010); Zheplinska et al. (2022a)
Sliced Prato cheese	Biodegradable starch-based film with bactericidal levels of cell-free supernatant of *Lactobacillus curvatus P99*	Preventing the growth and proliferation *of L. monocytogenes*	Brands et al. (2017)
Cheese	Films of zein nanofibers loaded with ethyl esters *of Laurus nobilis* and *Rosmarinus officinalis*	Significant decline in *S. aureus* and *L. monocytogenes* populations along with strong suppression of mesophilic bacteria	Goksen et al. (2020)

High lipid content is the main cause of rapid spoilage of fish and seafood, leading to significant moisture loss and affecting their organoleptic properties (Honcharova et al., 2025). Therefore, the use of active antimicrobial packaging methods, such as antimicrobial films based on biopolymers, to extend the shelf life of fish products by preserving and protecting them against surface microbial contamination is a viable option (Valdés et al., 2017).

Dairy products include milk and other dairy products, including fermented milk, cheese, cream, etc., which have high nutritional value and are one of the main components of the human diet (Iakubchak et al., 2025). Various external factors, such as moisture, oxygen, microorganisms and light, are the driving force behind spoilage and other undesirable changes, such as oxidation, microbial contamination, discoloration and off-flavors, which lead to rapid deterioration of the quality of dairy products (Chen et al., 2019). The introduction of innovative active packaging methods, such as antimicrobial packaging systems based on biopolymers or nanomaterials, in the dairy industry can help eliminate the shortcomings of traditional systems, preserving product quality and improving its shelf life, while not harming the environment. As can be seen from Table 3 among various dairy products, cheese has been most widely studied by researchers for shelf life extension through the use of edible antimicrobial films.

Plastic waste problems and solutions

Approaches to the production and use of plastics need to be urgently reviewed. The wider collection and recycling of end-of-life plastic products for reuse in new production to offset the use of virgin plastic is a crucial aspect both to reduce the amount of plastic waste entering the environment and to improve the efficiency of the use of fossil resources. This is a central element underpinning the circular economy. In this way, food can be produced more locally than globally, with less fuel (including transport fuel for importing and distributing food), water and fertiliser, and with a significant reduction in the use of plastic packaging. This approach, adopted by billions of people, could make a huge difference to ensuring future food security, as well as reducing waste and pollution (Rhodes, 2018).

Biodegradable polymers can be an alternative to fossil materials, but they have a higher cost. The use of agro-industrial waste in blends with biopolymers can provide cheaper materials with improved properties. Authors Zhang et al. (2023) developed films incorporating copper-based nanoparticles, which improved the functional characteristics of the films. The properties of composite films containing copper-based nanoparticles depend on the filler concentration, dispersion state, and interaction of nanoparticles with the biopolymer matrix in the film. The composite film loaded with copper-based nanoparticles effectively extends the shelf life, maintaining the quality of various fresh products and ensuring safety. However, studies on the migration and safety characteristics of copper-based packaging films have so far been conducted on plastic-based films such as polyethylene, and studies on biopolymer-based films are limited.

Gums are naturally occurring polysaccharides that are often used as thickeners, brighteners, gelling agents, emulsifiers, and stabilizers in the food sector. As a biodegradable and sustainable alternative to petrochemical-based films and coatings, gums may be a promising replacement. Edible packaging based on natural plant gums helps to extend the shelf life of fresh and processed foods, and also reduces microbiological changes and/or oxidation processes. Nehra et al. (2022) highlighted the possible applications of gum-based polymers and their functional properties in the development of edible films and coatings. In the future, the technology of developing edible films and coatings based on natural gums can be commercially applied to improve the shelf life and maintain the quality of food products.

Biodegradable packaging materials are attracting much attention due to the ever-increasing environmental concerns regarding plastic pollution. They are a sustainable, environmentally friendly and cost-effective alternative to traditional plastic packaging materials. The combined formulation of nano/microencapsulated antimicrobial and antioxidant natural molecules incorporated into biodegradable food packaging systems offers many benefits, preventing food spoilage, extending shelf life, reducing plastic and food waste, and preserving the freshness and quality of food (Baghi et al., 2022).

Conclusion

The paper presents an overview of the current state of active food packaging. Chitosan remains one of the most promising biopolymers for the food industry due to its unique combination of film-forming properties and natural bioactivity (antimicrobial and antifungal effects). It has been studied that pure chitosan films are inferior in barrier properties to traditional plastic. However, the creation of composite materials (with the addition of gelatin, starch or nanocellulose) allows significant improvement of mechanical strength and reducing vapor permeability, making these materials competitive.

The incorporation of essential oils of spices and aromatic substances into the chitosan matrix provides a powerful synergistic effect, enhancing antiseptic properties and providing the packaging with antioxidant characteristics. This is especially important for products with a high fat content and fresh vegetables.

Attention is paid to the sustainable development of active packaging systems that preserve the quality and organoleptic properties of food products. The incorporation of antimicrobial agents into edible biopolymer-based films is extremely effective in inhibiting or killing pathogenic microorganisms that cause contamination and spoilage of food products. This can reduce potential off-flavors resulting from the direct incorporation of active compounds into food products. The synergistic effectiveness of antimicrobial biodegradable packaging systems can be enhanced by the application of nanotechnology concepts such as bio-nanocomposites.

The paper highlights the potential of antimicrobial packaging systems to effectively inhibit target spoilage microorganisms by utilizing an appropriate combination of biopolymers and bioactive compounds to produce antimicrobial film and its use for various types of finished food products.

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