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REVIEW ARTICLE

Polysaccharide-based films: from packaging materials to functional food

Tatiana N. Popyrina[1] · Tatiana S. Demina[1,2,3] · Tatiana A. Akopova[1]

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Abstract A wider application of naturally derived polysaccharides is of great interest as materials for food packaging industry. Biocompatibility and biodegradability of polysaccharide-based films and coatings ally with a shift from application of non-biodegradable petrochemical polymers to the more environmentally friendly ones. Due to a range of inherent features in chemical structure and bioactivity, the polysaccharide materials could bring additional functionality to food packaging. The chelating ability of the polysaccharides provides also their application as carriers of additional active components, such as nanoparticles, essential oils and polyphenols. The improved physicochemical, antibacterial and antioxidant properties of the filled films allows to consider the edible polysaccharide-based films as functional food products. This review is aimed at analysis of evolution of polysaccharide-based food packaging materials from inert one starting from cellophane to recent research works on development of multicomponent polysaccharide-based functional food films and coatings.

✉ Tatiana N. Popyrina
popyrina@ispm.ru

Tatiana S. Demina
demina@ispm.ru

Tatiana A. Akopova
akopova@ispm.ru

[1] Enikolopov Institute of Synthetic Polymeric Materials, Russian Academy of Sciences, 70 Profsouznaya str., Moscow, Russia 117393

[2] Institute for Regenerative Medicine, I.M. Sechenov First Moscow State Medical University (Sechenov University), 8-2 Trubetskaya str., Moscow, Russia 119991

[3] Moscow Aviation Institute (National Research University), 4 Volokolamskoe shosse, Moscow, Russia 125993

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Abbreviations

UV	Ultra violet
CMC	Carboxymethylcellulose
HPMC	Hydroxypropylmethylcellulose
MC	Methylcellulose

Introduction

More than a century has passed since the beginning of industrial production of cellophane, a film material made of regenerated cellulose. In the middle of the twentieth century, polysaccharide-based packaging was almost completely replaced by materials based on petrochemical polymers, which are cheaper to produce and have new attractive properties. However, recent requirements for the transformation of packaging material's production and utilization to a more ecologically friendly approach are forcing the manufacturers to return to biodegradable polymers, which certainly include polysaccharides (Dey et al. 2021). In the food industry, polysaccharide films are widely used to preserve various food products. A new option of polysaccharides application in this field is production of edible packaging films and coatings. Such materials could not only to protect the food, but also to serve as functional food itself. They supply the human needs for proteins, fats and carbohydrates, as well as enhance immunity, and improve the function of internal organs contributing to reducing body weight. In recent years, there has been an increase in the number of research works aimed at providing a new functional and physico-mechanical properties to polysaccharide films and coatings by filling them with essential oils, polyphenols and nanoparticles of various origins. A range of polysaccharides and their derivatives used in the food industry is also expanding. This work is aimed at analysis of the present state of the art of application of the polysaccharide-based films and coatings in food industry starting from packaging materials to functional food.

Polysaccharides: structure, properties and application in the food industry

Polysaccharides are high-molecular weight carbohydrates composed of monosaccharide units linked by glycosidic bonds with a wide range of physicochemical and biological properties. They are derived from natural sources (plants, animals and microorganisms) and are edible and biocompatible (Zhou et al. 2022). The natural sources of the polysaccharides are easily renewable and environmentally friendly, so the polysaccharide-based materials can undergo a natural life cycle (Fig. 1), which is a positive factor for reduction of environmental pollution (Tajeddin and Arabkhedri 2020).

A lot of works with detailed description of the processes of isolation of the polysaccharides from natural sources have been already published (Kaur and Dhillon 2014; Chopra and Manikanika 2021; Dehghani Soltani et al. 2021). We would like to emphasize only a fundamental difference in the methods of extraction. Some polysaccharides, such as guar and starch, are isolated from raw sources directly by mean of extraction (Dehghani Soltani et al. 2021). Other polysaccharides, such as chitin and cellulose, require a multistage treatment of the raw material, while their derivatives are obtained by chemical transformations with several steps of synthesis, extraction, and purification (Zhang et al. 2021; Akopova et al. 2021).

The most frequently used polysaccharides in food industry are (Cutter 2006; Lu et al. 2019):

- starch – a mixture of semi-crystalline amylose (20–30%) and amorphous branched amylopectin (70–80%), consisting of D-glucopyranose units linked by α-1–4 glycosidic bonds; in amylopectin, side chains is also consisting of α-D-glucopyranose residues, which are attached to the main chain at regular intervals (1–6); obtained from cereals (mainly rice and corn) and root crops (potatoes and cassava);
- cellulose – consisting of D-glucopyranose units linked by glycosidic bonds β-1–4, is obtained both from plant sources (cotton, wood and a number of herbaceous plants) and using microorganisms (bacteria *Acetobacter, Sarcina ventriculi and Agrobacterium*);
- chitosan consists of D-glucosamine and N-acetyl-D-glucosamine units linked by β-(1–4) glycosidic bonds; product of deacetylation of chitin extracted from crustacean shells and some fungi and microorganisms;
- alginates consist of β-D-mannuronic acid and α-L-hyaluronic acid units linked (1–4) by glycoside bonds;

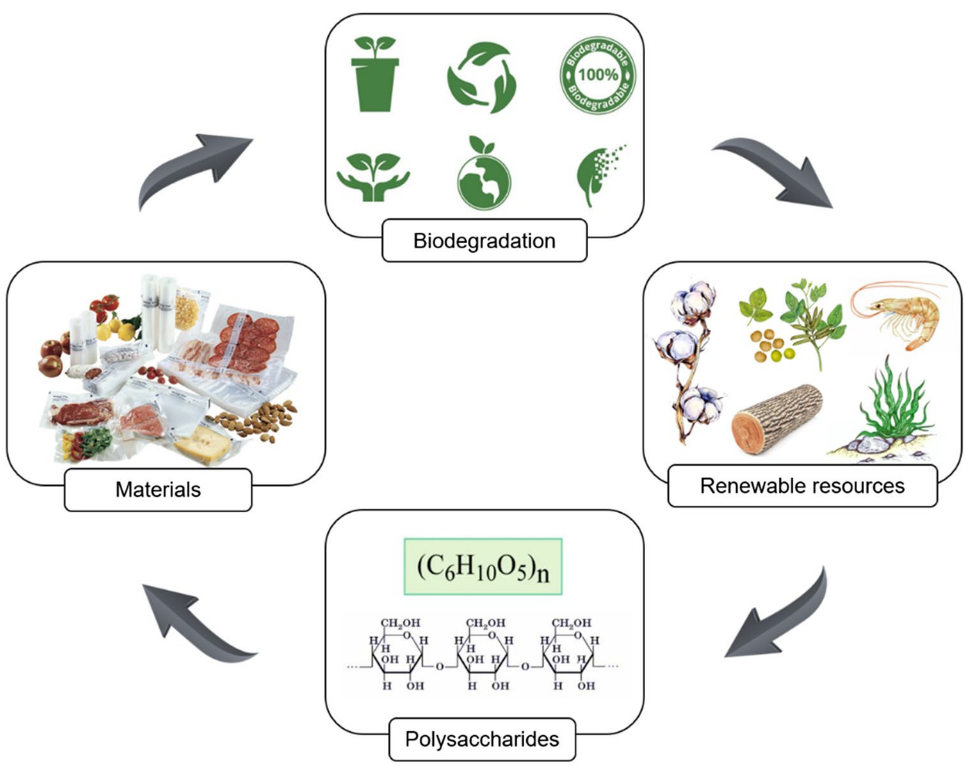

Fig. 1 Life cycle of polysaccharide-based materials

sodium and calcium salts of a natural polysaccharide, alginic acid, extracted from red, brown and some green algae of the genera *Laminaria* and *Macrocystis;*
- guar (guar gum)—consists of β-(1–4) glycosidically linked mannose residues to which galactose residues are (1–6)-linked at every second mannose unit; obtained from the seeds of the legume *Cyamopsis tetragonolobus.*

These polysaccharides could effectively act as thickeners, emulsifiers, stabilizers, gel-formers, encapsulating and moisture-retaining agents even in small amounts of 1–3 wt.% (Venugopal 2016). They allow to preserve and improve the properties of various food products (Lu et al. 2019). The high molecular weight and the ability to organize complex hydrogen bond systems determine the good film-forming properties of polysaccharides. They are widely proposed to producing films and coatings for the packaging of various products, fruits or vegetables (Mangaraj et al. 2019). More detailed properties and possible applications of the above-mentioned polysaccharides in the food industry are summarized in Table 1.

Thus, all the above-mentioned polysaccharides are promising and actively used in the food industry. They perform many functions, favorably influencing the consistency and useful properties of the food products. Application of polysaccharide-based materials as packaging materials are receiving a lot of attention in a recent works.

Polysaccharide-based packaging films and coatings

Packaging materials have certain requirements to ensure their successful use for preservation of packaged food products from deterioration during transportation, storage, or sale (Gokularaman et al. 2017). Significant differences in the shelf life and quality of food products are mainly affected by the absence of water vapor and oxygen, and, thus, the high vapor and gas barrier properties of the packaging material (Bourtoom 2008). In addition, these materials should have good mechanical properties, as they are often shaped and applied directly to the products themselves. The material should not deform, peel or decompose during the packaging process and further storage (Gokularaman et al. 2017). The material's antimicrobial properties provide protection from various pathogenic microorganisms and their toxins, so they could significantly increase the product shelf life (Cha and Chinnan 2004). In recent years, the preference is given to materials that are environmentally friendly and capable of further safe biodegradation within a short period of time. Therefore, the most promising types of packaging materials in the food industry are recognized to be biocomposite thin-layer films and coatings (Tajeddin and Arabkhedri 2020).

Due to the complexly organized system of hydrogen bonds providing the high cohesion energy, the polysaccharides are incapable of melting without decomposition. Therefore, methods for casting of polysaccharide films and fibers are limited to solution-based technologies. Food packaging films and coating production preferably required the use of non-toxic solvents, such as water, ethyl alcohol, water-alcohol solutions, diluted aqueous solutions of acetic acid, etc. (Bourtoom 2008; Gokularaman et al. 2017). To shape the films in the food industry, two casting methods are mainly used—continuous and discontinuous. In the continuous method, the solution is applied through a nozzle with special holes for uniform distribution on a continuously moving belt, followed by drying. In the discontinuous method, the polymer solution is cast onto special precipitation substrates, followed by drawing and drying (Fryer and Versteeg 2008). Polymer solutions could be also used to form coatings directly to the products by applying them on vegetables, fruits or berries by spraying and electrospraying methods, as well as by dipping (Khan et al. 2012).

Due to their intermolecular structure the polysaccharide films have gas barrier properties against O_2 and CO_2 allowing them to prevent rapid product spoilage and providing extended shelf life for fruits, vegetables, sausages, meat and fish products (Bourtoom 2008; Coma 2013; Mangaraj et al. 2019). In addition, such packaging is able to retain moisture loss from the products and prevents them from drying out (Venugopal 2016; Hassan et al. 2018). Polysaccharide films and coatings are often edible, oil- and fat-resistant, transparent, low-calorie and odorless (Coma 2013; Hassan et al. 2018). They have a high sorption capacity, so that when ingested they adsorb and remove from the body metal ions, radionuclides and other harmful compounds. In addition, polysaccharide films and coatings successfully serve as carriers of components and additives of various nature: dyes, flavors, sweeteners, antimicrobial and antioxidant agents used to improve the properties and organoleptic characteristics of food products (Gómez-Estaca et al. 2014; Hassan et al. 2018). The disadvantages of polysaccharide films are their low antimicrobial properties (except for chitosan (Dutta et al. 2009)), low mechanical strength, weak vapor barrier properties, unstable against water, acids and alkalis due to their hydrophilic nature (Venugopal 2016; Mangaraj et al. 2019). In addition, most polysaccharide films have an increased stiffness, which is counteracted by the addition of safe plasticizers, such as glycerol or sorbitol (Lim et al. 2020). To prevent water solubility or loss of mechanical strength instead in high humidity, various methods of the macromolecule cross-linking are used (Azeredo and Waldron 2016). To overcome the above disadvantages and to optimize the properties of polysaccharide-based packaging materials, they are also used in combination with each other.

Table 1 Main properties of the polysaccharides and their application in the food industry

Polysaccharide	Properties	Food processing applications	References
Starch	Non-ionic polymer capable of dissolving in hot water and dispersing in cold water;	Inert filler in bakery products;	Santana and Angela Meireles (2014), Tester et al. (2004)
	A reversible decrease in viscosity and gel-forming ability with increasing temperature;	Thickener in soups, sauces and pie fillings;	
	Gel-forming ability is higher in starches with high amylose content (wheat, corn);	Jelly-forming agent in puddings, confectionery and cheese products;	
	Slowly absorbed by the body in the process of breaking it down to glucose;	Emulsifier for salad dressings and mayonnaise;	
	Ability to exhibit thermoplastic properties when plasticizers (glycerin, water, etc.) are added due to a sharp decrease in the glass transition temperature	Stabilizer in dairy products, ice cream;	
		Moisture-retaining, structure-forming component in sausage products;	
		Filler in packaging materials	
Cellulose and its derivatives	In native form is unable to dissolve in water due to the complex structure of hydrogen bonds;	Structure-forming component in various products: milk powder, sausages, cookies;	Liu et al. (2021), Perumal et al. (2022)
	Ability to regenerate from a number of water-soluble derivatives to form insoluble films and fibers with good mechanical characteristics;	Emulsifier in sauces, cheese products, dairy desserts;	
	The possibility of extraction of micro- and nanocrystalline forms capable of gelation in water;	Texturizing agent and stabilizer for frozen foods;	
	Hypolipidemic activity due to the ability to adsorb cholesterol;	A filler that prevents caking in loose mixes and clumping in bakery products;	
	Hypoglycemic activity due to its inhibitory effect on starch digestion and processes of glucose diffusion and absorption;	As dietary fiber;	
	Neither native cellulose nor its derivatives are absorbed in the body	Packaging materials	
Chitosan	Good solubility in aqueous solutions of monoprotic mineral and organic acids;	Preservative and clarifier in fruit juices and wine;	Friedman and Juneja (2010), Venugopal (2016)
	High chelating and adsorption capacity towards to both organic substances and radionuclides and salts of heavy metals;	To regulate the fat content of milk and as a stabilizer and immunomodulator in dairy products;	
	Antibacterial and antifungal activity;	As dietary fiber and rheological modifier in gluten-free products;	
	A wide range of molecular weights of commercial products, and hence the viscosity of aqueous salt solutions;	As structure-forming and stabilizing additives in food compositions containing oils and fats;	
	Film- and fiber-forming ability;	In fish and seafood to increase shelf life, stability during storage, protection against pathogens;	

Table 1 (continued)

Polysaccharide	Properties	Food processing applications	References
	Ability to complex with fatty acids and therefore suppress the adsorption of steroids, bile acids and triglycerides in the body;	Packaging materials	
	Ability to lower cholesterol and glucose levels;		
	Is not digested in the body		
Alginates	High water-holding properties (up to 25 ml of water per gram of its own weight);	Thickener in jams, marmalade, fruit sauces, desserts, baked goods;	(Menon (2011), Rehm (2009)
	Water solubility;	Stabilizer for beer foam, mousse;	
	Good gel- and film-forming properties;	Emulsifier for mayonnaise and salad dressings;	
	Thermal stability;	As dietary fiber;	
	A wide range of solution viscosity;	For packaging products to ensure their preservation at high and low temperatures;	
	High sorption ability against radionuclides, salts of heavy metals, fatty acids;		
	Not digested in the body		
Guar	High water-holding properties (up to 40 ml per gram of own weight);	As a rheological modifier in the baking industry (frozen dough, bread, cakes and cakes), in the production of gluten-free products (pasta and bread);	(Miyazawa and Funazukuri (2006), Mudgil et al. (2014)
	Water solubility;	Stabilizer in the dairy industry (ice cream, milkshakes, yogurts);	
	High viscosity even at low solution concentrations (up to 1.5%);	Thickener in the production of beverages, sauces and ketchup;	
	Good gel- and film-forming abilities;	As dietary fiber;	
	Ability to lower cholesterol and blood glucose levels;	Packaging materials	
	Not absorbed in the body		

Table 2 shows some combinations of polysaccharides and their effect on the properties of the food films and coatings.

As can be seen from the data in Table 2, the combination of different polysaccharides allows improving a number of important food packaging properties, such as mechanical, barrier and antimicrobial (by adding chitosan) ones. However, this could be not enough for their further large-scale application. Various functional fillers into the polysaccharide matrix for targeted optimization of the material properties are proposed.

Functional film materials

The high sorption and chelating ability of the polysaccharides determines their application as carriers of various active components, along with fabrication of nanocomposite film materials (Hassan et al. 2018). Recently, a lot of research works are focusing on functionalization of polysaccharide-based packaging materials by filling them with nanoparticles of various nature, essential oils, and polyphenols. Such fillers can both improve the physicochemical and mechanical properties of the materials and play the role of antimicrobial and antioxidant agents. It allows upgrading the packaging materials to supplement food products bearing the bioactive components to positively affect the human health and quality of life.

Filling with nanoparticles

The nanotechnology allows producing a large variety of nanoparticles with a size ≤ 100 nm, and provides a tremendous benefit on their use as fillers for various materials. The nanoparticles are classified into two groups based on their chemical nature: inorganic (metals, metal oxides, clay, etc.) and organic (natural or synthetic polymers) ones. The nanoparticles dispersed within a polysaccharide matrix could improve the mechanical, optical, barrier and antimicrobial properties of film packaging materials (Chaudhary et al. 2020).

For example, it was found that the complexation processes of starch hydroxyl groups with silver nanoparticles (Abreu et al. 2015) resulted in enhancement of mechanical properties and adding antimicrobial activity to the materials. The inclusion of titanium oxide nanoparticles reduced the hydrophilicity of the starch films, which led to an increase in their vapor barrier properties and a decrease in solubility (Goudarzi et al. 2017). The ability of the filled nanoparticles to shield the ultraviolet range of light could protect the food from UV radiation.

Filling of guar and cellulose derivative-based films with silver or copper nanoparticles (Arfat et al. 2017) as well as with nanocrystalline polysaccharides (Sotnikova et al. 2017; Mel'nikov et al. 2020) resulted in improvement of mechanical, antimicrobial and gas barrier properties. Filling the thermoplastic starch films with chitin nanoparticles in concentrations of 5 to 20% led to significant enhancement of the mechanical and thermal properties of the material, mostly pronounced when a fibrous filler is used (Salaberria et al. 2015). Such films had enhanced barrier properties against water vapor and oxygen and significant antifungal activity.

The addition of copper sulfide nanoparticles to sodium alginate films improved UV protection and mechanical strength, as well as increased the hydrophobicity and vapor barrier properties of the material (Roy and Rhim 2020). This work also revealed the antibacterial activity of the filled films against Gram-negative bacteria.

Table 2 Effect of polysaccharides combinations on the properties of the based on films and coatings as well as on the food products

Polysaccharides combination	Effects	Referenes
Rice starch/chitosan	Improved vapor barrier capability; reduced water solubility; increased tensile strength and reduced film elasticity	Bourtoom and Chinnan (2008)
Cellulose/chitosan	Improved vapor barrier ability; antimicrobial activity against *Escherichia coli* and *Staphylococcus aureus*	Wu et al. (2004)
CMC/chitosan	Improved barrier properties; increased mechanical strength and resistance of the coating to water	Arnon et al. (2015)
Manioc starch/CMC	Reduced solubility in water; improved mechanical characteristics: increased tensile strength, reduced elongation at break	Tongdeesoontorn et al. (2011)
Sodium alginate/MC	Improvement of gas and vapor barrier properties of coatings	Maftoonazad et al. (2008)
Sodium alginate/cellulose	Improved vapor barrier ability; oil resistance; increased tensile strength	Sirviö et al. (2014)
Chitosan/guar	Good vapor barrier properties; decreased permeability to O_2; increased tear and puncture strength; antimicrobial activity against *Escherichia coli* and *Staphylococcus aureus*	Rao et al. (2010)
Pea starch/guar	Improved vapor barrier capability; reduced water solubility; increased tear and puncture strength due to increased film density	Saberi et al. (2016, 2017)

Chitosan-based films were filled with zinc oxide nanoparticles and hydrophobically modified with octadecylammonium clay (Rodrigues et al. 2020). Zinc oxide nanoparticles were homogeneously distributed over chitosan matrix in the presence of clay, which led to a significant improvement in the mechanical characteristics in comparison with films made of chitosan only. The addition of clay nanoparticles had no effect on the thermal degradation temperature of chitosan, whereas an improvement in thermal stability of the films was observed with the addition of zinc oxide nanoparticles. In the antimicrobial test, it was found that chitosan and zinc oxide nanoparticles had a synergistic effect against *Escherichia coli and Staphylococcus aureus.*

The synthesis of silver nanoparticles within a mixture of CMC and guar provide them the antimicrobial activity to pathogenic food bacteria and fungi as well as led to the improved mechanical properties (Kanikireddy et al. 2020). For example, the tensile strength of the filled films was 1.5-times higher while the modulus of elasticity was twice as low. The coating of strawberries by this nanocomposite mixture led to a decrease in weight loss and prolongation of the product's shelf life.

Thus, the analysis of literature sources showed that the addition of nanoparticles, both organic and inorganic nature, complexly affects the mechanical characteristics of the film materials, significantly increasing their tensile strength with some non-critical reduction in elasticity. Barrier properties, both in relation to water and gases, are also higher in all the above studies. Antimicrobial properties of the polysaccharide-based films can be improved by using chitosan both in pure form and in mixed polymer matrices, as well as by including silver nanoparticles and/or metal oxides and salts.

Encapsulation of essential oils

Essential oils – extracted from a variety of plants and spices are aromatic oily liquids that exhibit antimicrobial and immunomodulatory properties (Atarés and Chiralt 2016). Essential oils are highly effective against a wide range of Gram-positive and Gram-negative bacteria as well as some major foodborne pathogenic bacteria, i.e. *Salmonella enterittidis, Escherichia coli, Campylobacter jejuni* and *Staphylococcus aureus (*Burt 2004*)*. More than three thousand species of essential oils are known, of which only about three hundred are of commercial interest for food applications (Atarés and Chiralt 2016). However, because of their hydrophobic nature, intense aroma and flavor, there are limitations and difficulties in incorporating oils directly into many food products. Encapsulating essential oils into polysaccharide films is a perspective way to solve these problems, since the polymer can inhibit the taste and aroma of the oils, level out the hydrophobicity, and allow controlling the rate of their release (Liu et al. 2019).

Encapsulation of orange peel essential oil into chitosan films led to extended the shelf life of the shrimps from 7 to 15 days, and also inhibited lipid oxidation and microbial growth (Alparslan and Baygar 2017). Orange essential oil was also added to corn starch via emulsion approach to increase antibacterial activity against *Staphylococcus aureus* and *Listeria monocytogenes* (do Evangelho et al. 2019). However, a decrease in the morphological homogeneity of the films resulted in the formation of micropores and a decrease in the tensile strength and elongation rate. The encapsulation of bergamot essential oil in chitosan-based films enhanced antimicrobial activity against *Penicillium italicum* as well as improved vapor barrier properties (Sánchez-González et al. 2010).

Emulsion films based on HPMC with tea tree essential oil were also fabricated and studied in (Sánchez-González et al. 2009). Increasing the concentration of essential oil led to an increase in the vapor barrier properties of the films and a decrease in the sorption capacity to water. Thus, when the oil concentration in the matrix was more than 2%, the vapor permeability of the films decreased by 30–40%, while the films became less transparent and lost their luster. As in the previous work, a decrease in mechanical characteristics due to violations of the film's continuity was also observed. The addition of the garlic essential oil in the alginate food film at a concentration of more than 0.2% resulted in a significant inhibitory effect against *Staphylococcus aureus* and *Bacillus cereus* (Pranoto et al. 2005). The authors also noted that they did not observe any decrease in the mechanical properties of the obtained emulsion films.

Other studies on the encapsulation of essential oils in polysaccharides have shown similar results (Ojagh et al. 2010; Bonilla et al. 2012). Generally, the encapsulation leads to a decrease in the mechanical characteristics and an increase in their vapor-barrier and antimicrobial properties of the films.

Polyphenols filling

Polyphenols are bioactive compounds found in various plants and include phenolic acids, flavonoids, polyphenolic amides, phytoestrogens (resveratrol and lignans). Polyphenols are shown to be promising as antioxidants, anti-allergic, anti-inflammatory, antitumor, anti-diabetic and antimicrobial agents helpful for the prevention of various diseases (Pinto et al. 2021). Due to this broad spectrum of properties, polyphenols and polyphenol containing plant extracts are added to film materials for food packaging.

For example, extracts of guava leaves were added to sodium alginate films resulting in a significant increase of antioxidant and antibacterial activity as well as the increased tensile strength of the filled films. The extract reduced also the film's solubility in water, and improved vapor barrier capacity (Luo et al. 2019). The authors noted the denser structure of the films, which they attribute to the presence of intermolecular hydrogen bonds between the biologically active substances and the sodium alginate.

CMC-based films filled with Chinese onion root extract showed a decrease in the tensile strength and water solubility, while vapor barrier properties, antibacterial and antioxidant properties were improved (Riaz et al. 2020). The addition of green tea extracts to chitosan significantly increased the vapor barrier and antioxidant properties of the polysaccharide films, while their mechanical properties were decreased (Peng et al. 2013). The filling of starch films with mango peel powder improved the barrier properties of the films and promoted the homogenization of their structure (Rojas-Bravo et al. 2019). The composite films exhibited the high antioxidant properties depending on the filler concentration. The experiments showed the prospects of the developed composite films as edible coatings for peeled fruits. When starch films were filled with sunflower extract they showed the high antioxidant properties even at small amounts of the added extract (1–2 wt.%) (Menzel et al. 2019). The mechanical properties of the films decreased with increasing amounts of the extract. At the same time, all the composite samples had good gas and vapor barrier properties.

In general, studies of the polysaccharide-based films filled with various polyphenols also revealed high antioxidant properties of the modified films with a decrease in their mechanical properties, which were still enough for their usage as edible coatings (Liu et al. 2017; Wang et al. 2019).

Combinations of functional additives

Thus, the use of functional additives within the polysaccharide-based films leads to a significant improvement of their functional properties. However, the fillers could negatively affect the mechanical characteristics of the polymer matrices (Fig. 2). Therefore, it is advisable to combine different additives to achieve optimal material properties of functional packaging film for particular application. Table 3 summarizes the literature data on the properties and application of the composite films made using several functional additives within the polysaccharide matrix. The combination of nanoparticles with essential oils and/or polyphenols could balance the negative effect of the latter ones on the mechanical properties of the films. The combination of essential oils and polyphenols often leads to a significant increase in the antimicrobial properties of the films. Analysis of the literature data shows the effectiveness of this approach, and the large number of the studied functional additives could provide a variety of options for their combination. As a result, the range of polysaccharide-based functional films and coatings can be significantly expanded,

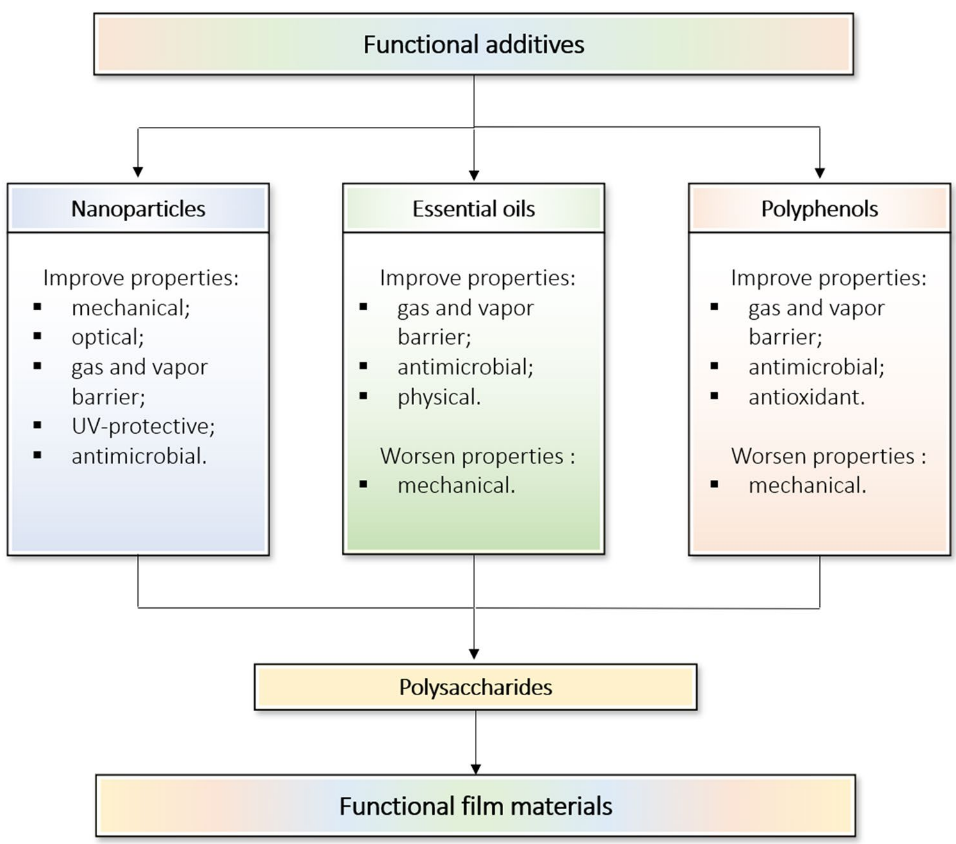

Fig. 2 Effect of various fillers on the properties of the functional polysaccharide-based film materials

Table 3 Combination of functional additives and their effect on the packaging material properties and the application options

Composition of the functional film	Properties	Application	References
Chitosan/guar/zinc oxide nanoparticles/rosella extract	The composite films showed improved antimicrobial, antioxidant, mechanical, and preservative properties compared to unfilled films	Protection of cheese from photo-oxidation, free radicals and microbes, extending its shelf life	El-Sayed et al. (2020)
Chitosan/clove essential oil/clay nanoparticles	The nanoparticles dispersed in the emulsion film matrix leveled the reduction in the mechanical properties of the films coming from the encapsulation of essential oil. An increase in vapor-barrier and antimicrobial properties of the materials was also noted	Extends the shelf life of sliced bread up to 3 months due to mold growth inhibition by films	Lee et al. (2018)
Chitosan/zinc oxide nanoparticles/sandalwood essential oil	Zinc oxide nanoparticles reduced the negative effect of the introduction of oil into the chitosan matrix on the mechanical properties of the films. Also, a decrease in light transmission, film roughness and an increase in antifungal activity against *Penicilium italicum* were observed	Extend the shelf life of mandarins and protect them from fungal decay	Aditya et al. (2022)
Chitosan/starch/pomegranate peel extract/essential oil of *Thymus kotschyanus*	The composite films had optimal mechanical characteristics and a high antibacterial effect against *L. Monocytogenes*	Extending the shelf life of beef meat to 21 days at 4 °C and inhibiting lipid oxidation	Mehdizadeh et al. (2020)
Cellulose/zinc oxide nanoparticles/extract grapefruit seeds	The composite films had high transparency with improved mechanical, UV-protective and vapor barrier properties. The films also exhibited effective antimicrobial and antioxidant protection	Functional packaging for food products	Roy et al. (2021)
Sodium alginate/kiwi peel extract/silver nanoparticles	The composite films had high tensile strength, good vapor barrier, UV-protective and antioxidant properties, and antibacterial activity against *Staphylococcus aureus* and *Escherichia coli*	Extends the shelf life of cherries, inhibits berry moisture loss and protects against microbial spoilage	Sun et al. (2021)

and their properties can be optimized according to the criteria applied to packaging materials for the food industry.

Conclusion

Polysaccharides are promising and actively used polymers in the food industry. They could serve as biodegradable packaging material with satisfactory mechanical characteristics. Moreover, combination of different polysaccharides allows improving a number of film properties, such as mechanical, barrier and antimicrobial ones. The high sorption and chelating ability of polysaccharides provides the possibility of incorporating various active components into the structure of polysaccharide-based films. Nanoparticles of different nature, essential oils and polyphenols are most commonly used for this purpose. Such fillers can both improve physical, chemical and mechanical properties of materials and play the role of functional antimicrobial and antioxidant agents. Combination of fillers of different nature in one matrix allows optimizing their consumer properties of the edible packaging films. This approach will allow to further supplement the food products with useful components having a favorable effect on the human health.

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