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Review article

EDIBLE FILMS AND COATINGS – SOURCES, PROPERTIES AND APPLICATION

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ABSTRACT: In order to extend product shelf life while preserving the quality scientific attention focused to biopolymers research that are base for edible films and coatings production. Another major advantage of this kind of food packaging is their eco-friendly status because biopolymers do not cause environmental problems as packaging materials derived from non-renewable energy sources do. Objective of this work was to review recently studied edible films and coatings – their sources, properties and possible application. As sources for edible biopolymers were highlighted polysaccharides, proteins and lipids. The most characteristic subgroups from each large group of compounds were selected and described regarding possible physical and mechanical protection; migration, permeation, and barrier functions. The most important biopolymers characteristic is possibility to act as active substance carriers and to provide controlled release. In order to achieve active packaging functions emulsifiers, antioxidants and antimicrobial agents can also be incorporated into film-forming solutions in order to protect food products from oxidation and microbial spoilage, resulting in quality improvement and enhanced safety. The specific application where edible films and coatings have potential to replace some traditional polymer packaging are explained. It can be concluded that edible films and coatings must be chosen for food packaging purpose according to specific applications, the types of food products, and the major mechanisms of quality deterioration.

Key words: *biopolymers, edible films and coatings, sources, properties, application*

INTRODUCTION

The largest part of materials used in packaging industry are produced from fossil fuels and are un-degradable. For this reason packaging materials represent a serious global environmental problem (Kirwan & Strawbridge, 2003). A big effort to extend the shelf life and enhance food quality while reducing packaging waste has encouraged the exploration of new bio-based packaging materials, such as edible and biodegradable films from renewable resources (Tharanathan, 2003). The use of these materials, due to their biodegradable nature, could at least to some extent solve the waste problem. Biodegradable packaging materials are naturally comprised of polymers that should be capable of being ultimately degraded by microorganisms through composting processes to produce natural breakdown compounds such as carbon dioxide, water, methane and biomass. There are two types of biodegradable polymers; those which are non-edible or edible (Nur Hanani et al., 2014). An edible/biodegradable film is one which is typically produced from food-derived ingredients using wet or dry manufacturing process. The resulting edible film (EF) should be a free-standing sheet that can be placed on or between food components (McHugh, 2000). In contrast, edible coatings (EC) are thin layers of edible materials which can be applied directly to the surfaces of food products by dipping, spraying or panning. Edible packaging formats can be consumed with, or as part of the food product, but they may fulfil other functions; like acting as carriers for targeted food additives (antimicrobial agents, antioxidants, flavourings, etc.). EF and EC may also be used to inhibit moisture, oxygen or carbon dioxide migration and to improve the mechanical integrity or handling characteristics of the food (O'Sullivan et al., 2006). To be accepted, an edible film should be generally recognized as safe (GRAS) and used within any limitations specified by the U.S. Food and Drug Administration (FDA). Ultimately any material that is used for direct food contact will face regulatory scrutiny, particularly biopolymers that act as carriers of additives intended to migrate to the food for preservative effects.

Functions and advantages of EF and EC (Han, 2014):

1. Edibility and biodegradability - To maintain their edibility and biodegradability, all film components should be food-grade ingredients and biodegradable (environmentally safe).

2. Physical and mechanical protection - Mechanical properties should be optimized regarding tensile strength, elongation-at-break, elastic modulus, compression strength, puncture strength, stiffness, tearing strength, burst strength, abrasion resistance, adhesion force, folding endurance, etc.

3. Migration, permeation, and barrier functions - All barrier properties are affected by film composition and environmental conditions (relative humidity and temperature).

4. Convenience and quality preservation - EF and EC can retard surface dehydration, moisture absorption, oxidation of ingredients, aroma loss, frying oil absorption, ripening/aging, and microbial deterioration of food products. They also contribute to visual quality, surface smoothness, flavour carriage, edible color printing, and other marketing-related quality factors.

5. Shelf-life extension and safety enhancement - An increased protective function of food products extends shelf life and reduces the possibility of contamination by foreign matter.

6. Active substance carriers and controlled release - Edible films and coatings can be utilized for food ingredients, pharmaceuticals, nutraceuticals, and agrochemicals in the form of capsules, microcapsules, soluble strips, flexible pouches, and coatings on hard particles.

Biodegradable films can be produced by using two basic techniques. The first technique uses wet solvent processing; commonly known as solution casting. Solution casting was developed over one hundred years ago. Using this method, solutions are spread onto leveled plates like acrylic, silicon or teflon plates, followed by a drying process at ambient conditions or under a controlled conditions: controlled relative humidity, hot air, infrared energy, microwave energy (Dangaran and Tomasula, 2009). After the 1950s, the use of extrusion was employed for the manufacture of thermoplastic polymers and extrusion became the dominant production method used for plastics manufacture. Extrusion uses elevated temperature and shear to soften and melt the polymer (resins), thereby allowing a cohesive film matrix to form (Dangaran and Tomasula, 2009).

SOURCES

Edible coatings and films are usually classified according to their structural material (Falguera et al., 2011). Main molecule groups as sources for EF and EC are polysaccharides, proteins and lipids. Figure 1 shows possible sources for EF and EC.

Biopolymers have multiple film-forming mechanisms, including intermolecular forces such as covalent bonds (e.g., di-sulfide bonds and cross linking) and electrostatic, hydrophobic, or ionic interactions.

- Starch + PE
- Polyanhydrides
- Polyvinyl alcohol
- Poly-lactic acid (PLA)

NON-EDIBLE

↑

BIOPOLYMERS

↓

EDIBLE

↙ ↓ ↘

Polysaccharides	Protein	Lipid
Starch & modified starch	Soy proteins	Oils
Chitin & chitosan	Pea proteins	Free fatty acids
Pectins	Sunflower	Bees wax
Galactomannans	Whey protein	Carnauba wax
Kefiran	Wheat gluten	Paraffin
Cellulose & modified cellulose	Corn zein	Shellac resin
Alginate	Collagen & gelatins	Terpene resin
Carrageenan	Casein	Acetoglycerides
Gellan gum	Egg white protein	
Xanthan gum	Fish miofibrilar protein	
Pullulan	Peanut protein	

Figure 1. Biopolymer sources

For the resulting films or coatings to be edible, the film-forming mechanism involved in fabrication should be an appropriate food process: pH modification, salt addition, heating, enzymatic modification, drying, use of food-grade solvents, or reactions with other food-grade chemicals. The nature of edible packaging films, which is rigid and brittle, causes limitations in food applications. Therefore, to overcome film's brittleness and also to increase the workability and flexibility of these films, various types of plasticizers have been widely used (Ghasemlou et al., 2011; Parra et al., 2004). These film structures are brittle due to extensive interactions between polymer molecules (Krochta, 2002). Mechanical properties could be improved by doping some hydrophilic and hygroscopic plasticizer which can attract water molecules, as a result of having interactions between plasticizer–biopolymer instead of between biopolymer –biopolymer. The addition of plasticizers affects not only the elastic modulus and other mechanical properties, but also the resistance of EF and EC to permeation of vapours and gases (Sothornvit and Krochta, 2000, 2001).

In order to achieve active packaging or coating functions emulsifiers, antioxidants and antimicrobial agents can also be incorporated into film-forming solutions (Han, 2003). There are several categories of antimicrobials that can be potentially incorporated into edible films and coatings, including organic acids (acetic, benzoic, lactic, propionic, sorbic), fatty acid esters (glyceryl monolaurate), polypeptides (lysozyme, peroxidase, lactoferrin, nisin), plant essential oils (cinnamon, oregano, lemongrass), nitrites and sulphites, among others (Franssen & Krochta, 2003). Active function of the edible film and coating system protects food products from oxidation and microbial spoilage, resulting in quality improvement (organoleptic preference and the visual perception of quality) and enhanced safety (Kim et al., 2012; Lee et al., 2012).

PROPERTIES

1. Polysaccharide films

Polysaccharides are great materials for the formation of EC and EF, as they show excellent mechanical and structural properties, but they have a poor barrier capacity against moisture transfer (Falguera et al., 2011).

1.1. Starch and derivatives

The application of starch-based films in food packaging is promising because of their environmental appeal, low cost, flexibility and transparency (Müller et al., 2009; Bilbao-Sáinz et al., 2010). Edible films made from starch are tasteless, odourless and transparent, thus prevent a change of taste, flavour and appearance of food products (Chiumareli and Hubinger, 2012). Tensile strength and flexibility of starch films are determined by macromolecular chain mobility in the amorphous phase, amylose: amylopectin ratio, plasticizer and water content. Main advantages of starch films are excellent barrier properties to O_2 and CO_2. On the other hand it has weaker barrier properties to the water due to high hydrophilicity (Šuput et al., 2013).

1.2. Chitosan

Chitosan is a polysaccharide obtained by deacetylation of chitin, which is extracted from the exoskeleton of crustaceans and fungal cell walls. It has been extensively used in films and coatings due to its ability to inhibit the bacterial and fungal pathogens growth (Romanazzi et al., 2002). Chitosan interferes with the negatively charged residues of macromolecules exposed on the fungal cell surface and changes the permeability of the plasma membrane. Presence of fatty acids was also shown to enhance the antimicrobial properties of chitosan (dos Santos et al., 2012). Besides natural antimicrobial property, biodegradability, biocompatibility with human tissues, biofunction, null toxicity, chitosan has a vast potential that can be applied in the food industry (Aider, 2010). Hitosan film lack is sensitivity to environmental humidity so they have low moisture barrier, which has limited their wide use in food applications.

1.3. Pectin

Pectins are a complex group of polysaccharides in which D-galacturonic acid is a principal constituent. They are structural components of plant cell walls and also act as intercellular cementing substances. Under certain circumstances, pectin forms gels. This property has made pectins a very important additive in jellies, jams, marmalades, and confectionaries, as well as edible coatings and films (Han, 2014).

1.4. Cellulose and its derivatives

Cellulose is the major cell wall component in plants. Besides plant source cellulose, bacterial cellulose was also utilized to develop EF and EC. Due to a large number of intra-molecular hydrogen bonds cellulose is water insoluble. Etherification of cellulose results in formation of water soluble ethers: methylcellulose (MC), carboxymethylcellulose (CMC), hydroxypropylmethylcellulose (HPMC) and hydroxypropylcellulose (HPC) which have good film forming properties and are widely produced commercially (Olivas and Barbosa-Canovas, 2005). Coatings and films based on cellulose derivatives are generally transparent, flexible, odour-free, tasteless, water soluble, and resistant to O_2 and CO_2. WVP of these films is highly influenced by the hydrophobic: hydrophilic ratio of film components (Krochta et al., 1994; Callegarin et al., 1997). CMC has been found to reduce oil uptake in fried potatoes, particularly in combination with a blanching or calcium chloride pre-treatment. HPC can be extruded into films because of its thermoplastic characteristics. MC is a better barrier to moisture as it is less hydrophilic. However, the most interesting feature for their application in thermally treated foods, particularly in fried products, is the reversible thermal gelation capability of MC and HPMC in aqueous systems, widely utilized to reduce oil absorption during the frying of various foods, such as meat, poultry, starchy foods, doughs, etc. (Chidanandaiah Keshri et al., 2005; Rimac-Brncic et al., 2004).

1.5. Alginate

Alginate can form coatings with or without gelation through evaporation of the solvent, electrolyte cross linking (calcium) or injection of a water-miscible non-solvent for alginate. It has been used mainly for meat products, as a sacrificing agent to retard dehydration and as protection against lipid oxidation (Varela and Fisz-man, 2011).

1.6. Carrageenan

Carragenan coatings can also act as sacrificing agents. They have little application in multilayered foods and are mostly used to retard microbial growth in gel matrices containing antimicrobial agents and as oxygen barriers to delay lipid oxidation in meat and precooked meat products (Varela and Fiszman, 2011).

2. Protein films

Proteins are polymers containing more than 100 amino acid residues (Nur Hanani et al., 2014) and they must be denaturated by heat, acid, alkali and/or solvent in order to form the more extended structures which are required for film formation (Bourtoom, 2008). Compared with synthetic films, protein-based films exhibit poor water resistance and lower mechanical strength. Yet, proteins are still generally superior to polysaccharides in their ability to form films with greater mechanical and barrier properties (Cuq et al., 1998). Physical and chemical properties of protein films are influenced by amino acid composition, electrostatic charge, amphyphylic properties, as well as secondary, tertiary and quaternary structure changes due to pressure, heat, irradiation, mechanical damage, acid, alkali, salt, metal ion, enzyme action etc (Krochta et al., 1994). Proteins are good film formers exhibiting excellent gas and lipid barrier properties (Popović et al., 2012), particularly at low relative humidity. Protein films are brittle and susceptible to cracking due to the strong cohesive energy density of the polymer. The cross linking of proteins by means of chemical (glutaraldehyde, formaldehyde, glyceraldehyde, glyoxal), enzymatic (transglutaminase), or physical (heating, irradiation) treatment was reported to improve the water-vapour barrier as well as the mechanical properties and resistance to proteolysis of films (Bourtoom, 2009; Ouattara et al., 2002, Senna et al., 2010).

2.1. Collagen

Collagen is the most commercially successful edible protein film. Films based on high concentrations of hydrolyzed collagen produce films with more homogeneous surfaces (Fadini et al., 2013). Collagen fibers and collagene powder were also shown to be suitable for the production of biocomposite films in a system where the fibers act as filler, exerting a reinforcement effect (Wolf et al., 2009).

2.2. Gelatin

Gelatin is produced by partial acid or alkali hydrolysis of collagen at high temperatures in the presence of water. This protein has a random configuration of polypeptide chains in aqueous solutions and gives flexible, strong films impermeable for O_2 (Krochta et al., 1994). Gelatin has also been reported to possess antioxidant activity. A recent study by Gomez-Guillén et al. (2011) also revealed antimicrobial activity associated with gelatin. However, the relationship between peptide characteristics and antimicrobial activity has not been clearly demonstrated. Gennadios et al. (1994) also reported that gelatin was one of the first materials used as carrier of bioactive components. Natural antioxidants and/or antimicrobial substances were able to extend the functional properties of these biodegradable films and create an active packaging bio-material (Gómez-Guillén et al., 2011). Like other protein films, gelatin films have poor water vapour barrier properties. However, this drawback can overcome surfactant addition, such as lecithin (Andreuccetti et al., 2011).

2.3. Casein

Casein molecules easily form transparent, flexible, tasteless films from aqueous solutions without further treatment (Krochta et al., 1994; Gennadios et al., 1994). Due to a high number of polar groups casein films excellently adhere to different substrates and prevent migration of O_2, CO_2

and aromas (Arrieta et al., 2013). Decreased film solubility in water and improved mechanical properties were obtained through buffer treatments at the isoelectric point of these films (Chen, 2002); by cross linking the protein using irradiation (Vachon et al., 2000); through the use of transglutaminase, Trametes hirsute laccase, and *Trichoderma reesei* tyrosinase enzyme (Patzsch et al., 2010); or by the use of a chemical crosslinker such as formaldehyde, DL-glyceraldehyde, glutaraldehyde, or glyoxal (Audic and Chaufer, 2010; Mendes de Souza et al., 2010). Main disadvantage of casein is its relatively high price.

2.4. Gluten

Wheat gluten is a mixture of two main proteins differing in their solubility in aqueous alcohols: soluble gliadins and insoluble glutenins (Wieser, 2007). Wheat gluten films are homogenous, transparent, strong and good water barriers. The development of edible coatings or films with selective gas permeability is very promising for controlling respiratory exchange and improving the conservation of fresh or minimally processed fruits and vegetables (Tanada-Palmu and Grosso, 2005). The rheological properties of gluten films can be altered from smooth to rubber like by high pressure treatment (Koehler et al., 2010).

2.5. Zein

Zein is a hydrophobic protein found in maize, obtained as a by-product of the bioethanol and oil industry. It is traditionally used as a coating material in the confectionary industry (Arcan, and Yemenicioglu, 2011). It consists of alcohol-soluble proteins (Padua and Wang, 2002). Zein is rich in nonpolar amino acids, which contribute to water insolubility and improve the water vapor barrier of films (Dangaran et al., 2009). Physico-chemical properties of alcoholic zein solutions are highly influenced by a concentration of alcohol, which, in turn, affects film properties. Interest is growing in incorporating antioxidant and antimicrobial agents into zein coatings or films to produce functional films for food application (Lungu and Johnson, 2005). Treatment of film-forming solutions by gamma irradiation can improve the water barrier properties, color, and appearance of zein films (Soliman et al., 2009).

3. Lipid films

The efficiency of lipid materials in edible films and coatings depends on the nature of the lipid used, and in particular on its structure, chemical arrangement, hydrophobicity, physical state (solid or liquid), and lipid interactions with the other components of the film (Rhim and Shellhammer, 2005). Lipids are usually combined with other film-forming materials, such as proteins or polysaccharides, as emulsion particles or multilayer coatings in order to increase the resistance to water penetration (Mehyar et al., 2012). Polar resin films are good barriers for O_2, CO_2 and ethylene. Hydrophobic substances potentially used for the lipid-based edible films and coatings include natural waxes (carnauba, candelilla, rice bran and beeswax); petroleum-based waxes (paraffin and polyethylene wax); petroleum-based, mineral, and vegetable oils; acetoglycerides and fatty acids; and resins, such as shellac and wood rosin (Rhim and Shellhammer, 2005).

Wax is the collective term for a series of naturally or synthetically produced nonpolar substances. Waxes either have no polar constituents or possess a hydrophilic part so small or so buried in the molecule that it cannot readily interact with water, thereby preventing the molecule from spreading to form a monolayer on the surface. Their high hydrophobicity, which makes them insoluble in bulk water and soluble in typical organic solvents, explains why waxes are the most efficient barriers to water-vapour transfer (Han, 2014). The most common method for making wax microemulsions is the water-to-wax method, in which water is added to the molten wax and/or resin in the presence of the fatty acid and a base to invert the emulsion to wax-in-water (Hagenmaier and Baker, 1994).

These formulations add a good gloss to fruits and vegetables, but limitations to their use are poor mechanical properties and oily appearance in some products.

Table 1.
Application of Edible Films and Coatings

Materials for EF and EC	Foods	References
	Fruits and vegetables	
Cassava starch	Strawberry	Garcia et al., 2012
	Tangerine	Silva et al., 2012
Corn starch+beeswax	Raspberry	Pérez-Gallardo et al., 2012
Chitosan	Asparagus	Qiu et al., 2012
	Pomegranate	Ghasemnezhad et al., 2013
	Broccoli	Alvarez et al., 2013
	Sliced apple	de Britto and Assis, 2012
Pectin	Mellon	Ferrari et al., 2013
	Peach	Ayala-Zavala et al., 2013
	Mango	Moalemiyan et al., 2012
Caseinate	Dried pineapple	Talens et al., 2012
Alginate	Mushroom	Jiang, 2013
	Cherry	Diaz-Mula et al., 2012
Gelatin	Persimmon	Neves et al., 2012
	Meats, poultry, fish	
Chitosan	Carp	Zhang et al., 2012
Chitosan	Sausage	Krkić et al., 2012
Gelatin	Chilled hake	Lopez de Lacey et al., 2012
WPI	Dried fish	Matan, 2012
WPC	Frozen salmon	Kim et al., 2012
Red algae	Bacon	Shin et al., 2012
	Bakery, snacks and dairy	
Pectin	Fried potato chips	Garmakhany et al., 2012
WPI	Cheese	Ramos et al., 2012
Red algae	Cheese	Shin et al., 2012

APPLICATION

Prior to the application of biopolymers, some factors need to be considered such as microbiological stability, solubility, transparency, wettability, oil and grease resistance, cohesion, mechanical properties, sensory and permeability to water vapourand gases. Preparation of biodegradable and/or edible films involves the use of at least one film-forming agent (macromolecule), a solvent and a plasticizer. The optimization of edible films composition is in one of the most important steps of the research in this field, since they must be formulated according to the properties of the food to which they have to be applied (Rojas-Grau et al., 2009). Table 1 summarises numerous recent researches on EF and EC applications.

1. Fresh and minimally processed fruits and vegetables

In the case of fruits and vegetables, coatings are used to prevent weight loss (retain moisture), inhibit microorganisms, slow down aerobic respiration, and improve appearance by providing gloss. Edible coatings for fresh fruits are useful for controlling ripeness by reducing oxygen penetration into the fruit, thus reducing metabolic activity and softening changes (Conforti and Zinck, 2002). In the literature, many reviews bring together the effect of new edible emulsion coatings on storability and postharvest quality of fresh fruits and vegetables (Lin and Zhao, 2007; Valencia-Chamorro et al., 2011). Similarly, interest in the use of edible coatings in fresh-cut fruits and vegetables has grown, since these coatings can also act as carriers of food-grade antioxidants and antimicrobials that help reduce enzymatic browning and microbial growth (Rojas-Grau et al., 2009).

2. Meat, poultry and fish products

Natural collagen casings from animal intestine represent one of the earliest uses of edible protein packaging materials (McHugh and Avena-Bustillos, 2012). Studies of colagen edible films have shown their potential to reduce moisture loss, minimize lipid oxidation, prevent discoloration, and reduce dripping of muscle foods (Gennadios et al., 1997). In addition, incorporation of antimicrobials into edible coatings, gels, or films can also help control the safety of meat products (Cutter, 2006). Edible coatings can be applied to meat and fish products by dipping, spraying, casting, rolling, brushing, and foaming. Edible coatings can also be used to reduce fat uptake during deep frying of meat (Dragich and Krochta, 2010) and drip loss during thawing of salmon (Rodriguez-Turienzo et al., 2011).

3. Cereals, bakery and dairy coatings

In this sense, edible coatings are used in cereal products to prevent hydration and improve quality (McHugh and Avena-Bustillos, 2012). Rice fortified with vitamins and minerals has been coated with zein-wood rosin mixtures to prevent vitamin and mineral losses during washing in cold water (Padua and Wang, 2002). Emulsified edible coatings composed of corn starch, MC, and soybean oil extended the shelf life of coated crackers stored at 65%, 75%, and 85% RH compared to uncoated ones by reducing moisture uptake (Bravin et al., 2006). Commercial confectionary coatings made with a variety of vegetable oils instead of cocoa butter were used for enrobing wheat and soy cereal bars, thus improving lightness and general acceptance of the product (Aramouni and Abu-Ghoush, 2010).

4. Oil-fried products

Deep fat fried products are very appealing to consumers due to a soft, moist interior covered with crispy crust, but can contain up to 50% fat. Some edible coatings, particularly those based on hydrophilic polymers, are a good barrier to fats and oils. This application has become increasingly important in recent years, as oil uptake in fried products has become a health concern, related to obesity and coronary disease (García et al., 2008). For example, coating potato strips with MC and HPMC edible coatings reduced oil uptake during frying by 35 – 40% without a significant influence on texture properties (Garcia et al., 2002), and gellan gum and guar gum coatings also showed promising results (Kim et al., 2011).

CONCLUSION

The use of edible films and coatings as suitable packaging for the food industry has become a topic of great interest because of their potential for increasing shelf life of food products. These coatings and films exhibit various functions when used, such as inhibition of the migration of moisture, oxygen, carbon dioxide, aromas, lipids, and so forth; the ability to carry food ingredients; and the ability to improve the mechanical properties of the food. Many functions of edible films and coatings are similar to those of synthetic packaging films; however, edible film and coating materials must be chosen for food packaging purpose according to specific applications, the types of food products, and the major mechanisms of quality deterioration. Biodegradable and/or edible films have the potential to reduce some traditional polymeric packaging materials for specific applications. However, in order to do so, bio-based packaging must perform like conventional packaging and provide all of the necessary functions of containment, protection, preservation, information, convenience ina legally and environmentally-compliant manner, cost-effectively.

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REFERENCE

1. Aider, M. (2010). Chitosan application for active bio-based films production and potential in the food industry: review. *LWT-Food Science and Technology, 43 (6)*, 837-842.
2. Alvarez, M.V., Ponce, A.G., Moreira, M.R. (2013). Antimicrobial efficiency of chitosan coating enriched with bioactive compounds to improve the safety of frsh cut broccoli. *LWT-Food Science and Technology, 50 (1)*, 78-87.
3. Andreuccetti, C., Carvalho, R.A., Galicia-Garcia, T., Martinez-Bustos, F., Grosso, C.R.F. (2011). Effect of surfactants on the functional

properties of gelatin-based edible films. *Journal of Food Engineering, 103 (2)*, 129-136.
4. Aramouni, F.M., Abu-Ghoush, M.H. (2010). Physicochemical and sensory characteristics of no-bake wheat-soy snack bars. *Journal of Science and Food Agriculture. 91 (1)*, 44-51.
5. Arcan, I., Yemenicioglu, A. (2011). Incorporating phenolic compounds opens a new perspective to use zein as flexible bioactive packaging materials. *Food Research International 44 (2)*, 550-556.
6. Arrieta, M.P., Peltzer, M.A., Lopez, J., Garrigos, M.C., Valente, A.J.M., Jimenez, A. (2013). Functional properties of sodium and calcium caseinate antimicrobial active films containing carvacrol. *Journal of Food Engineering, 121 (1),* 94-101.
7. Audic, J.L., Chaufer, B. (2010). Caseinate based biodegradable films with improved water resistance, *Journal of Applied Polymer Science, 117 (3)*, 1828-1836.
8. Ayala-Zavala, J.F., Silva-Espinoza, B.A., Cruz-Valenzuela, M. R., Leyva, J.M., Ortega-Ramírez, L.A., Carrazco-Lugo, D.K., Pérez-Carlón, J.J., Melgarejo-Flores, B.G., González-Aguilar, G.A., Miranda, M.R.A. (2013). Pectin–cinnamon leaf oil coatings add antioxidant and antibacterial properties to fresh-cut peach. *Flavour and Fragrance Journal, 28 (1)*, 39-45.
9. Baldwin, E.A., Nisperos-Carriedo, M.O., Baker, R.A. (1995). Use of edible coatings to preserve quality of lightly (and slightly) processed products. *Critical Reviews in Food Science and Nutrition, 35 (6),* 509.
10. Bilbao-Sáinz, C., Avena-Bustillos, R.J., Wood, D.F., Williams, T.G., McHugh, T.H. (2010). Composite edible films based on hydroxypropyl methylcellulose reinforced with microcrystalline cellulose nanoparticles. *Journal of Agricultural and Food Chemistry, 58 (6)*, 3753–3760.
11. Bourtoom, T. (2008). Edible films and coatings: Characteristics and properties. *International Food Research Journal,* 15 (3), 237–248
12. Bourtoom, T. (2009). Protein edible film: Properties enhancement. *International Food Research Journal, 16 (1),* 1-9.
13. Bravin, B., Peressini, D., Sensidoni, A. (2006). Development and application of polysaccharide–lipid edible coating to extend shelf-life of dry bakery products. *Journal of Food Engineering, 76 (3),* 280–290.
14. Callegarin, F., Gallo, J.A.Q., Debeaufort, F., Voilley, A. (1997). Lipids and biopackaging. *Journal of American Oil Chemists Society, 74 (10)*, 1183-1192.
15. Chen, H. (2002). Formation and Properties of casein films and coatings. In *Protein-based films and coatings.* Ed. A. Genadios, CRC Press, Boca Raton, pp.181-211.
16. Chidanandaiah Keshri, R.C., Sanyal, M.K., Kotwal, S.K., Sudhan, N.A. (2005). Quality changes in enrobed/coated products during storage. *Indian Food Industry, 24 (1),* 57-61.
17. Chiumarelli, M., Hubinger, M. (2012). Stability, solubility, mechanical and barrier properties of cassava starch – Carnauba wax edible coatings to preserve fresh-cut apples. *Food hydrocolloids, 28 (1),* 59-67.
18. Conforti, F.D., Zinck, J.B. (2002). Hydrocolloid-Lipid Coating Affect on Weight Loss, Pectin Content, and Textural Quality of Green Bell Peppers. *Journal of Food Science, 67(4),*1360–1363.
19. Cuq, B., Gontard, N., Guilbert, S. (1998). Proteins as Agricultural Polymers for Packaging Production. *Cereal Chemistry, 75 (1),* 1–9.
20. Cutter, C.N. (2006). Opportunities for bio-based packaging technologies to improve the quality and safety of fresh and further processed muscle foods. *Meat Science, 74 (1),* 131–142.
21. Dangaran, K., Tomasula, P.M., Qi, P. (2009). Structure and Function of Protein-Based Edible Films and Coatings. In *Edible films and coatings for food application.* Eds. M.E. Embuscado, H.C. Huber, Springer, New York, pp 25-56.
22. De Britto, D., Assis, O.B.G. (2012). Chemical, biochemical, and microbiological aspects of chitosan quaternary salt as active coating on sliced apples. *Ciencia e Technologia de Alimentos, 32 (3),* 599-605.
23. Diaz-Mula, H.M., Serrano, M., Valero, D. (2012). Alginate Coatings Preserve Fruit Quality and Bioactive Compounds during Storage of Sweet Cherry Fruit. *Food and Bioprocess Technology, 5 (8),* 2990-2997.
24. dos Santos, N.S.T., Aguiar, A.J.A.A., de Oliveira, C.E.V., de Sales, C.V., de Melo e Silva, S., da Silva, R.S., Stamford, T.C.M., de Souza, E.L. (2012). Efficacy of the application of a coating composed of chitosan and *Origanum vulgare* L. essential oil to control *Rhizopus stolonifer* and *Aspergillus niger* in grapes (*Vitis labrusca* L.). *Food Microbilogy, 32 (2),* 345–353.
25. Dragich, A.M., Krochta, J.M. (2010). Whey Protein Solution Coating for Fat-Uptake Reduction in Deep-Fried Chicken Breast Strips. *Journal of Food Science, 75 (1),* S43–S47.
26. Fadini, A.L., Rocha, F.S., Alvim, I.D., Sadahira, M.S., Queiroz, M.B., Alves, R.M.V., Silva, L.B. (2013). Mechanical properties and water vapour permeability of hydrolysed collagen–cocoa butter edible films plasticised with sucrose. *Food Hydrocolloids, 30 (2*), 625–631.
27. Falguera,V., Quinterob, J.P., Jimenez, A., Munoz, J.A., Ibarz, A. (2011). Edible films and coatings: Structures, active functions and trends in their use. *Trends in Food Science & Technology, 22 (6),* 292-303.
28. Ferrari, C.C., Sarantopoulos, C.I.G.L., Carmello-Guerreiro, S.M., Hubinger, M.D. (2013). Effect of osmotic dehydration and pectin edible coatings on quality and shelf life of fresh-cut melon. *Food Bioprocess Technology, 6 (1),* 80-91.
29. Franssen, L. R., Krochta, J. M. (2003). Edible coatings containing natural antimicrobials for processed foods. In *Natural antimicrobials for minimal processing of foods*. Ed. S. Roller, CRC Press, Boca Raton, pp.250-262.
30. Garcia, L.C., Pereira, L.M., de Luca Sarantopoulos, C.I.G., Hubinger, M.D. (2012). Effect

of Antimicrobial Starch Edible Coating on Shelf-Life of Fresh Strawberries. *Packaging Technology and Science, 25 (7)*, 413-425.

31. García, M., Bifani, V., Campos, C., Martino, M.N., Sobral, P., Flores, S. (2008). Edible coating as an oil barrier or active system Food engineering: Integrated approaches. In *Food engineering series.* Ed. G. Barbosa-Canovas, Springer, New York, pp.225-241.
32. Garcia, M.A., Ferrero, C., Bertola, N., Martino, M., Zaritzky, N. (2002). Edible coatings from cellulose derivatives to reduce oil uptake in fried products. Innovative Food Science & Emergency Technologies*, 3 (4)*, 391.
33. Gennadios, A., Hanna, M.A., Kurth, L.B. (1997). Application of edible coatings on meats, poultry and seafoods: a review. *LWT—Food Science and Technology 30 (4)*, 337-350.
34. Gennadios, A., McHugh, T.H., Weller, C.L., Krochta, J.M. (1994). Edible coatings and films based on proteins. In *Edible Coatings and Films to Improve Food Quality.* Eds. J.M. Krochta, E.A.Baldwin, M.O. Nisperos-Carriedo, Technomic Publishing, Lancaster, pp. 201–277.
35. Ghasemlou, M., Khodaiyan, F., Oromiehie, A., Yarmand, M.S. (2011). Development and characterization of a new biodegradable edible film made from kefiran an exopolysaccharide obtained from kefir grains. *Food Chemistry, 127 (4),* 1496–1502.
36. Ghasemnezhad, M., Zareh, S., Rassa, M., Sajedi, R.H. (2013). Effect of chitosan coating on maintenance of aril quality, microbial population and PPO activity of pomegranate (Punica granatum L. cv. Tarom) at cold storage temperature. *Journal of the Science of Food and Agriculture, 93 (2)*, 368-374.
37. Gomez-Guillen, M.C., Gimenez, B., Lopez-Caballero, M.E., Montero, M.P. (2011). Functional and bioactive properties of collagen and gelatin from alternative sources: a review. *Food Hydrocolloids, 25 (8),* 1813–1827.
38. Hagenmaier, R.D., Baker, R.A. (1994). Wax microemulsions and emulsions as citrus coatings. *Journal of Agricultural and Food Chemistry, 42 (4)*, 899-902.
39. Han, J.H. (2003). Antimicrobial food packaging. In *Novel food packaging techniques*. Ed. R. Ahvenainen, Woodhead publishing, Cambridge, UK, pp.50-70.
40. Han, J.H. (2014). Innovations in food packaging, Elsevier, Academic Press, USA.
41. Jiang, T., Effect of alginate coating on physicochemical and sensory qualities of button mushrooms (*Agaricus bisporus*) under a high oxygen modified atmosphere. *Postharvest Biology and Technology, 76 (1*), 91-97.
42. Kim I.H., Yang, H.J., Noh, B.S., Chung, S.J., Min, S.C. (2012). Development of a defatted mustard meal-based composite film and its application to smoked salmon to retard lipid oxidation. *Food Chemistry, 133 (4)*, 1501–1509.
43. Kim, D.N., Lim, J., Bae, I.Y., Lee, H.G., Lee, S. (2011). Effect of hydrocolloid coatings on the heat transfer and oil uptake during frying of potato strips. *Journal of Food Engineering, 102 (4)*, 317-320.
44. Kim, I.H., Yang, H.J., Noh, B.S., Chung, S.J., Min, S.C. (2012). Development of a defatted mustard meal-based composite film and its application to smoked salmon to retard lipid oxidation. *Food Chemistry, 133 (4),* 1501–1509.
45. Kirwan, M.J., Strawbridge, J.W. (2003). Plastics in food packaging. In *Food Packaging Technology*. Eds. R. Coles, D. McDowell, M.J. Kirwan, Blackwell Publishing, CRC Press, 174-240.
46. Koehler, P., Kieffer, R., Wieser, H. (2010). Effect of hydrostatic pressure and temperature on the chemical and functional properties of wheat gluten III. Studies on gluten films, *Journal of Cereal Science, 51 (1),* 140-145.
47. Krkić, N., Lazi, V., Savatić, S., Šojić, B., Petrović Lj, Šuput, D. (2012). Application of chitosan coating with oregano essential oil on dry fermented sausage. *Journal of Food and Nutrition Research, 51 (1),* 60-68.
48. Krochta, J.M. (2002). Proteins as raw materials for films and coatings: definitions, current status and opportunities. In *Protein-based films and coatings.* Ed. A. Genadios, CRC Press, Boca Raton, pp.1-41.
49. Krochta, J.M., Baldwin, E.A., Nysperos-Carriedo, M. (1994). Edible coatings and films to improve food quality, CRC Press, Boca Raton, pp 1-7, 25-101, 189-330.
50. Lee, H.B., Noh, B.S., Min, S.C. (2012). Listeria monocytogenes inhibition by defatted mustard meal-based edible films. *International Journal of Food Microbiology, 153(1-2),* 99-105.
51. Lin, S.Y., Zhao, Y. (2007). Innovations in development and application of edible coatings for fresh and minimally processed fruits and vegetables. *Comprehensive Reviews in Food Science and Food Safety, 6 (1),* 60-75.
52. Lopez de Lacey, A.M., Lopez-Caballero, M.E., Gomez-Estaca, J., Gomez-Guillen, M.C., Montero, P. (2012). Functionality of *Lactobacillus acidophilus* and *Bifidobacterium bifidum* incorporated to edible coatings and films. *Innovative Food Science&Emerging Technologies, 16 (1)*, 277-282.
53. Lungu, B., Johnson, M.G. (2005). Potassium sorbate does not increase control of Listeria monocytogenes when added to zein Coatings with nisin on the surface of full fat turkey frankfurter pieces in a model system at 4 °C. *Journal of Food Science, 70 (2),* M95-M99.
54. Matan, N. (2012). Antimicrobial activity of edible film incorporated with essential oils to preserve dried fish (Decapterus maruadsi). *International Food Research Journal, 19 (4*), 1733-1738.
55. McHugh, T.H. (2000). Protein-lipid interactions in edible films and coatings. *Nahrung, 44 (3)*, 148-151.
56. McHugh, T.H., Avena-Bustillos, R.J. (2012). Applications of edible films and coatings to processed foods. In *Edible Coatings and Films to Improve Food Quality*. Eds. E.A. Baldwin, R. Hagenmaier, J. Bai, CRC Press, Boca Raton, pp. 291-318.

57. Mehyar, G.F., Al-Ismail, K., Han, J.H., Chee, G.W. (2012). Characterization of Edible Coatings Consisting of Pea Starch, Whey Protein Isolate, and Carnauba Wax and their Effects on Oil Rancidity and Sensory Properties of Walnuts and Pine Nuts. *Journal of Food Science, 77 (2)*, E52–E59.
58. Mendes de Souza, P., Fernandez, A., Lopez-Carballo, G., Gavara, R. Hernandez-Munoz, P. (2010). Modified sodium caseinate films as releasing carriers of lysozyme. *Food Hydrocolloids, 24 (4),* 300–306.
59. Moalemiyan, M., Ramaswamy, H.S., Maftoonazad, N. (2012). Pectin-based edible coating for shelf-life extension of ataulfo mango. *Journal of Food Process Engineering, 35 (49*), 572-600.
60. Müller, C.M.O., Borges Laurindo, J., Yamashita, F. (2009). Effect of cellulose fibers addition on the mechanical properties and water vapor barrier of starch-based films. *Food Hydrocolloids, 23 (5),* 1328-1333.
61. Neves Jr., A.C.V., Coneglian, R.C.C., Soares, A.G., Freitas, D.G.C., Fonseca, M.J.O., Barreira, F.R., de Miranda, A.F.M. (2012). Physical and sensory characterization of edible coatings applied to minimally processed persimmon (Conference Paper). *Acta Horticulturae, 934*, 537-542.
62. Nur Hanani, Z.A., Roos, Y.H., Kerry, J.P. (2014). Use and application of gelatin as potential biodegradable packaging materials for food products, *International Journal of Biological Macromolecules*, 10.1016//j.ijbiomac. 2014. 04.027.
63. O'Sullivan, A., Shaw, N.B., Murphy, S.C., van de Vis, J.W., van Pelt-Heerschap, H., Kerry, J.P. (2006). *Journal of aquatic food product technology, 15 (1),* 21–32.
64. Olivas, G.I., Barbosa-Cánovas, G.V. (2005). Edible Coatings for Fresh-Cut Fruits. *Critical Reviews in Food Science and Nutrition, 45 (7-8),* 657-670.
65. Ouattara, B., Canh, L.T., Vachon, C., Mateescu, M.A., Lacroix, M. (2002). Use of γ-irradiation cross-linking to improve the water vapor permeability and the chemical stability of milk protein films. *Radiation Physics and Chemistry, 63 (3-6),* 821-825.
66. Padua, V.G., Wang, Q. (2002). Formation and properties of corn zein films and coatings. In *Protein-based films and coatings*. Ed. A. Genadios, CRC Press, Boca Raton, pp.43-67.
67. Parra, D.F., Tadini, C.C., Ponce, P. Lugao, A.B. (2004). Mechanical properties and water vapor transmission in some blends of cassava starch edible films. *Carbohydrate Polymers, 58 (4)*, 475-481.
68. Patzsch, K., Riedel, K., Pietzch, M. (2010). Parameter Optimization of Protein Film Production Using Microbial Transglutaminase. *Biomacromolecules*, 11 (4), 896-903.
69. Pereira Silva, D.F., Lopes Siqueira, D., Pires Matias, R.G., Oliveira, S.P., Rosa de Lins, R.C., Chamhum Salomao, L.C. (2012). Performance of edible films in comparison to the polyvinyl chloride film in the post-harvest tangerines 'Ponkan'. *Ciencia Rural, 42 (10)*, CR-6578.
70. Perez-Gallardo, A., Mattinson, S.D., Lazcano-Peralta, A., Fellman, J.K., Barbosa-Canovas, G., Garcia-Almendarez., B., Regalado, C. (2012). Effect of native and acetylated-crosslinked waxy corn starch-beeswax coatings on quality attributes of raspberries during storage. *Starke, 64 (8),* 665-673.
71. Popović, S., Pericin, D., Vastag, Z., Lazić, V., Popović, Lj. (2012). Pumpkin oil cake protein isolate films as potential gas barrier coating. *Journal of Food Engineering, 110 (3),* 374-379.
72. Qui, M., Jiang, H., Ren, G., Huang, J., Wang, X. (2012). Effect of chitosan coatings on postharvest green asparagus quality. *Carboxydrate Polymers, 92 (2),* 2027-2032.
73. Ramos, O.L., Pereira, J.O., Silva, S.I., Fernandes, J.C., Franco, M.I., Lopes-da-Silva, J.A., Pintado, M.E., Malcata, F.X. (2012). Evaluation of antimicrobial edible coatings from a whey protein isolate base to improve the shelf life of cheese. *Journal of Dairy Science, 95 (11),* 6282–6292.
74. Rhim, J.W., Shellhammer, T.H. (2005). Lipid-based edible films and coatings. In *Innovations in Food Packaging*. Ed. J.H. Han, Elsevier, London, pp.362–383.
75. Rimac-Brncic, S., Lelas, V., Rade, D., Simundic, B. (2004). Decreasing oil absorption in potato strips during deep fat frying. *Journal of Food Engineering, 64 (2),* 237-241.
76. Rodriguez-Turienzo, L., Cobos, A., Moreno, V., Caride, A., Vieites, J.M., Diaz, O. (2011). Whey protein-based coatings on frozen Atlantic salmon (*Salmo salar*): Influence of the plasticiser and the moment of coating on quality preservation. *Food Chemistry, 128 (1),* 187-194.
77. Rojas-Grau, M.A., Soliva-Fortuny, R., Martin-Belloso, O. (2009). Edible coatings to incorporate active ingredients to fresh-cut fruits: a review. *Trends in Food Science and Technology, 20 (10),* 438-447.
78. Romanazzi, G., Nigro, F., Ippolito, A., Di Venere, D., Salerno, M. (2002). Effects of pre- and postharvest chitosan treatments to control storage grey mold of table grapes. *Journal of Food Science, 67(5*), 1862-1866.
79. Senna, M.M., Salmieri, S., El-naggar, A.W., Safrany, A., Lacroix, M. (2010).Improving the Compatibility of Zein/Poly(vinyl alcohol) Blends by Gamma Irradiation and Graft Copolymerization of Acrylic Acid. *Journal of Agricultural and Food Chemistry*, 58 (7), 4470–4476.
80. Shin, Y.J., Song, H.Y., Seo, Y.B., Song, K.B. (2012). Preparation of red algae film containing grapefruit seed extract and application for the packaging of cheese and bacon. *Food Science and Biotechnology, 21 (1)*, 225-231.
81. Soliman, E.A., Eldin, M.S.M., Furuta, M. (2009). Biodegradable Zein-Based Films: Influence of γ-Irradiation on Structural and Functional Properties. *Journal of Agricultural and Food Chemistry, 57 (6),* 2529–2535.
82. Sothornvit R., Krochta J.M. (2000). Plasticizer Effect on Oxygen Permeability of β-Lacto-

globulin Films. *Journal of Agricultural and Food Chemistry, 48 (12),* 6298–6302.

83. Sothornvit R., Krochta J.M. (2001). Plasticizer effect on mechanical properties of β-lacto-globulin films. *Journal of Food Engineering, 50 (3)*, 149–155.
84. Talens, P., Perez-Masia, R., Fabra, M.J., Vargas, M., Chiralt, A. (2012). Application of edible coatings to partially dehydrated pineapple for use in fruit–cereal products. *Journal of Food Engineering, 112 (1-2)*, 86-93.
85. Tanada-Palmu, P.S., Grosso, C.R.F. (2005). Effect of edible wheat gluten-based films and coatings on refrigerated strawberry (Fragaria ananassa) quality. *Postharvest Biology and Technology 36 (2),* 199-208.
86. Tharanathan, R.N. (2003). Biodegradable films and composite coatings: past, present and future. *Trends in Food Science & Technology, 14(3)*, 71-78.
87. Vachon, C., Yu, H.L., Yefsah, R., Alain, R., St-Gelais, D., Lacroix, M. (2000). Mechanical and Structural Properties of Milk Protein Edible Films Cross-Linked by Heating and γ-Irradiation. *Journal of Agricultural and Food Chemistry, 48 (8),* 3202–3209.
88. Valencia-Chamorro, S.A., Palou, I., del Río, M.A., Pérez-Gago, M.B. (2011). Antimicrobial Edible Films and Coatings for Fresh and Minimally Processed Fruits and Vegetables: A Review. *Critical Reviews in Food Science and Nutrition, 51 (9)*, 872-900.
89. Varela, P., Fiszman, S.M. (2011). Hydrocolloids in fried foods. A review. *Food Hydrocolloids 25 (8),* 1801-1812
90. Wieser, H. (2007). Chemistry of gluten proteins. *Food Microbiology, 24 (2)*, 115–119.
91. Wolf, K.L., Sobral, P.J.A., Telis, V.R.N. (2009). Physicochemical characterization of collagen fibers and collagen powder for self-composite film production. *Food Hydrocoloids, 23 (7),* 1886–1894.
92. Zhang, L., Luo, Y., Hu, S., Shen, H. (2012). Effects of chitosan coatings enriched with different antioxidants on preservation of grass carp (Ctenopharyngodon idellus) during cold storage. *Journal of Aquatic Food Product Technology, 21 (5)*, 508-518.

ЈЕСТИВИ ФИЛМОВИ И ОМОТАЧИ – ИЗВОРИ, ОСОБИНЕ И ПРИМЕНА

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Сажетак: Са циљем да се продужи рок трајања уз очување квалитета производа, пажња овог прегледног рада је усмерена на истраживања биополимера, који су основа за добијање јестивих филмова и омотача. Друга велика предност овакве врсте амбалаже је еколошки статус биополимера, јер са својим „еколошки пријатељским“ статусом не изазивају негативан утицај на животну средину, као што то чине материјали добијени из необновљивих извора енергије. Циљ овог рада је разматрање најскоријих достигнућа из области јестиве амбалаже (филмова и омотача) кроз истраживање њихових извора, својстава и могуће примене. Изворе јестивих биополимера чине три велике групе једињења: полисахариди, протеини и липиди. У свакој групи, типични представници су размотрени у погледу физичке и механичке заштите коју пружају; у погледу миграције, пропустљивости и баријерних особина. Најважнија заједничка карактеристика биополимера је могућност да делују као носачи активних супстанци и да обезбеде њихово контролисано ослобађање. У циљу постизања функције активне амбалаже, различити емулгатори, антиоксиданти и антимикробни агенси се могу уградити у филмогене растворе у циљу заштите прехрамбених производа од оксидације и микробиолошког квара, што резултира побољшањем квалитета и продужењем безбедности намирница. Након испитивања особина, рад се бави питањем специфичне примене, када јестиви филмови и омотачи имају потенцијал да замене традиционалну комерцијану полимерну амбалажу. Може се закључити да јестиви филмови и омотачи намењени за паковање хране морају бити бирани у складу са специфичношћу намене, на основу врсте прехрамбених производа, као и главних механизама нарушавања квалитета упакованих производа.

Кључне речи: б*иополимери, јестиви филмови и омотачи, извори, карактеристике, примена*

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