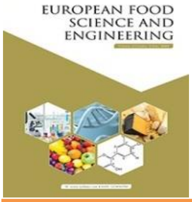

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Food edible coating systems: A review

Zineb Mahcene[1*], Sara Hasni[1], Mohamed Bilal Goudjil[2] and Aminata Khelil[1]

[1] Kasdi Merbah University Ouargla, Natural Sciences and Life Sciences Faculty, Biological Sciences Department, Lab of Protecting Ecosystems in Arid and Semi Arid areas, Ouargla 30000, Algeria

[2] Kasdi Merbah University Ouargla, Applied Sciences Faculty, Process Engineering Department, Lab. Process Engineering, Ouargla 30000, Algeria

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ABSTRACT

To extend the shelf life of products while maintaining their quality, scientific research is focused on the use of coating materials for food, in particular petrochemical polymers, but they are non-renewable, non-ecological and non-biodegradable. However, a common trend has appeared to reduce the use of these materials and replace them with renewable, ecological, more natural and healthier and biodegradable polymers notably edible polymers which are generally classified as polysaccharides, proteins and lipids. Furthermore, edible polymers have very limited conservative property, however, strengthening its property by antioxidants and antimicrobial turns indispensable to reduce oxidation and microbial spoilage, which results in an improved quality and increased security. This work aims to review the advantages of the edible films use in food technology enriched or not by preservatives by determining their sources, their classification and their possible applications. In conclusion, edible films can be considered as alternatives to plastic and should be selected for the purpose of food packaging, specific applications, types of food and principal quality degradation mechanisms

1. Introduction

A food is an edible substance of plant or animal origin rich in essential nutrients. It is consumed to sustain life, provide energy and promote growth. This richness makes food products fragile and quickly perishable due to microbial spoilage and oxidation. The microbiological and hygienic quality of a food constitutes one of the essential bases of its capacity to satisfy the consumers safety (Cahill, Upton, & Mcloughlin, 2002; Pal & Devrani, 2018). To deal with food spoilage problems, several techniques preservation are used by slowing the breakdown of food and thus prolonging their shelf life (Bonne, 2013). Recently, the development of coating technology associated with film-forming materials is a new direction in food technology (Alvarez, Ponce, & Moreira, 2013; Di Maio et al., 2014; Mahcene, Khelil, Hasni, Akman, et al., 2020). Of these, petroleum-based plastics have always attracted attention because of their low cost, high flexibility, ease of processing and their mechanical properties. However, the transfer of plastic components to the food during storage and their non-biodegradability has recently become a global concern and a serious threat to consumer health and the environment quality (Aydin, Kahve, & Ardic, 2017). For this reason, consumers demand more environmentally friendly and healthier food packaging techniques (Gaikwad & Lee, 2017; Mahalik & Nambiar, 2010). Growing consumer demand for safe, convenient and stable food and awareness of the negative environmental effects of non-biodegradable packaging (Bhagath & Manjula, 2019; Dehghani, Hosseini, & Regenstein, 2018).

Edible films which are biopolymers based on proteins, polysaccharides or lipids offer many advantages over synthetic materials as they are biodegradable and environmentally friendly (Athmaselvi, Sumitha, & Revathy, 2013; Mei, Yuan, Wu, & Li, 2013; Navarro-Tarazaga, Massa, & Pérez-Gago, 2011; Saputra, Kismiyati, Annur Ahadi, & Mochammad Amin, 2015). Additionally, edible films have limited antioxidant and antimicrobial properties. However, strengthening its activities by incorporating bioactive substances is therefore proving to be a more promising method in barrier technologies to improve food safety and quality (Alexa et al., 2018; Alvarez et al., 2013; Brasil, Gomes, Puerta-Gomez, Castell-Perez, & Moreira, 2012; Costa, Lucera, Conte, Zambrini, & Del Nobile, 2017; Gaikwad & Lee, 2017).

The objective of this review is to provide a complete overview of the different aspects of edible films with an explanation of their trends and recent developments on the one hand and bioactive molecules on the other hand in order to

*Corresponding author
E-mail address: mahcene.zineb@gmail.com

also study the application of these biopolymers enriched or not with bioactive molecules for food preservation.

2. Edible Films

The coating is a thin layer of edible polymers with biological and chemical functions. The edible films may be made of polysaccharides, proteins and / or lipids, enzymes, bacteriocins and other bio-edible components. The association between the polymer and the components can be obtained by mixing, extrusion, rolling or coating with other polymers (Bhagath & Manjula, 2019; Dehghani et al., 2018; Dhaka & Upadhyay, 2018).

3. Main Categories of Edible Films

Regarding food application, edible films are classified according to their main ingredients and their structure. The four main categories are edible films based on polysaccharides, lipids, proteins and composites which are mixtures of lipid and hydrocolloid components (Figure 1)

3.1. Edible films based on polysaccharides

Polysaccharides are generally used as thickeners due to their increased viscosity when hydrated. Since edible polysaccharide films are generally very hydrophilic, possess little moisture barrier properties, but have selective permeability to oxygen and carbon dioxide and are resistant to fats transfer. The selection of these films is adopted after checking their suitability in terms of physical, mechanical and functional properties (Bhagath & Manjula, 2019; Dehghani et al., 2018; Jeevahan, Chandrasekaran, Durairaj, Mageshwaran, & Joseph, 2017; Kurt, Toker, & Tornuk, 2017). Table 1 groups together the different categories of edible films based on polysaccharides.

3.2. Edible films based on proteins

The modification of proteins results in edible films with improved functional and technological properties. This aspect of protein-bound films is attracting increasing interest from scientists and manufacturers (Table 2). In general, edible protein membranes are similar to polysaccharide dependent ones in that they have relatively weak water vapor barrier properties while moisture loss is two to four times higher than that of polyethylene. Polypropylene, polyester and polyvinylidene chloride. Its mechanical property is very important as those manufactured by polysaccharides because of their consistency and uniform (Arfat, Benjakul, Prodpran, Sumpavapol, & Songtipya, 2014; Bhagath & Manjula, 2019; Dehghani et al., 2018; Dursun & Erkan, 2014; Jeevahan et al., 2017).

3.3. Edible films based on lipids

Lipids are not considered to be proper biopolymers because they cannot form cohesive and independent films. Therefore, they are used as packaging or introduced into other biopolymers for the manufacture of composite films. Incorporation of lipids into edible films can improve cohesion, water resistance and flexibility, as well as result in a film with a very good moisture barrier. It can retain the organoleptic characteristics and microbiological stability of food. Edible lipid-based films have been used in particular to limit the transmission of moisture through food (Chamanara, Shabanpour, Gorgin, & Khomeiri, 2012; de Azeredo, 2012; Dehghani et al., 2018; Jeevahan et al., 2017; Sánchez-Ortega et al., 2014; Tammineni, Ünlü, & Min, 2013).

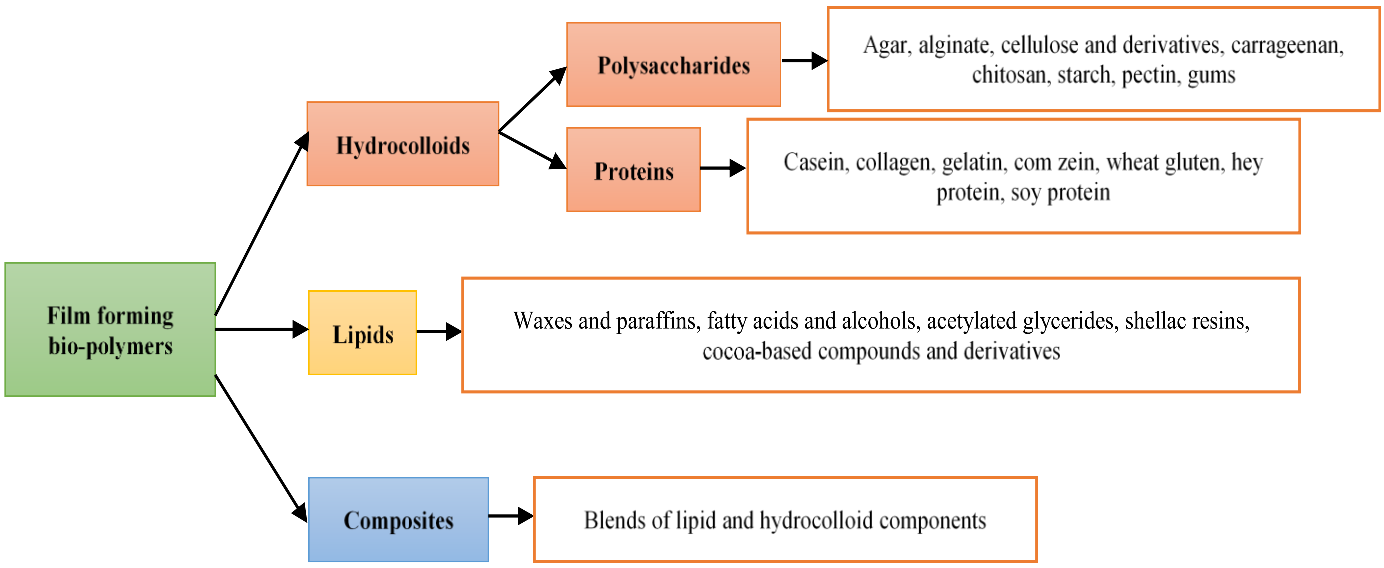

Figure 1. Film-forming biomaterials which have been widely studied for the formation of edible coatings and films.

Table 1. Different categories of edible films based on polysaccharides

Type	Origin	Structure	Property	Application	Reference
Cellulose	Vegetal	D-glucose units linked by β-1, 4. Native and modified (CMC, MC or HPC)	Odorless, transparent, flexible, not very resistant to water, but very resistant to greases, oils, oxygen and carbon dioxide	Used in injection molding and extrusion	Campos et al. (2011); Ghanbarzadeh &Almasi (2011); Navarro-Tarazaga et al. (2011)
Starch	Vegetal	A linear α-1,4 glucose polymer (20-25%) and amylopectiin (a branched polymer of α-1,4 glucoses linked by α-1,6 glucosides 75-80%)	Colorless, edible, tasteless	Meat (Beef, pork) packaging	Basiak, Galus, & Lenart (2015); Dhaka & Upadhyay (2018); Jimenez, Fabra, Talens, & Chiralt (2012); Youssef, Assem, El-Sayed, Salama, & Abd El-Salam (2017)
Pectin	Vegetal	α- (1,4) D-galactopyranosyluronic acid units linked by (1,2) L-rhamnopyranosyl units. Crosslinked pectin with versatile cations	Excellent barrier to oxygen, oil and aromas, important mechanical properties, poor resistance to humidity	Packaging of fresh fruits and vegetables.	Giancone et al. (2011); LiuLiu, Liu, Fishman, & Hicks (2007); Valdes, Burgos, Jiménez, & Garrigos (2015)
Alginate	Algal	β -D mannuronic (1,4) α-L-guluronic. Sodium alginate / calcium alginate	Poor water vapor barriers	Packaging of restructured foods and meat, fish and fruit products.	Dan Cristian, Oana Lelia, Francisc Vasile, & Carmen (2015); Hambleton, Voilley, & Debeaufort (2011); (Sirvio, Kolehmainen, Liimatainen, Niinimäki, & Hormi, 2014)
Carrageenan	Algal	Composed of alternating galac to pyranosyl dimers linked by alternating glycosidic bonds b-(1,4) and a- (1,3). Depending on sulphate content: κ-carrageenan (20%), ι- carrageenan (33%), λ-carrageenan (41%)		Meat, poultry and fish, sausage casings, solid foods and oil-based foods	Dhaka and Upadhyay (2018); Karbowiak, Debeaufort, Champion, & Voilley (2006); Youssef et al. (2017)
Agar	Algal		Insoluble in cold water but soluble in hot water	Activator of gels which are used for sweets and desserts	Phan, Debeaufort, Luu, & Voilley (2005)
Pullulan	Microbial	Maltotriosis α (1,6) glycosidic	Heat sealable, odorless, colorless, tasteless, water permeable and not very permeable to oil and oxygen	Fruit and vegetable preservation	Diab, Biliaderis, Gerasopoulos, & Sfakiotakis (2001); Kanmani & Lim (2013)
Gellan	Microbial	Linear repeat units of glucose tetrasaccharide, rhamnose and glucuronic acid	Hard and fragile, good mechanical properties and clarity	Fresh-cut Fuji apples	Campos et al. (2011); Lee, Shim, & Lee (2004); Maftoonazad & Badii (2009)
Chitosan	Invertebral	2-deoxy-2-acetamido (1,4) β-D-glucan	Antifungal, clear, solid and flexible, good resistance to oxygen, grease and oil, but very sensitive to humidity, non-toxic,	Coating of fresh fruits, vegetables and meat (Beef, fish, pork and poultry)	Dan Cristian et al. (2015); Dhaka & Upadhyay (2018); Kittur, Kumar, & Tharanathan (1998); Nayik, Majid, & Kumar (2015)

CMC: carboxymethylcellulose; MC: methylcellulose; HPC: hydroxypropylcellulose

4. Natural Compounds in Edible Films

The food quality is one of the essential bases of its ability to satisfy consumer safety because these food products are exposed to microbial deterioration and also oxidation. The main cause of deterioration of our food is the proliferation of certain microorganisms which contaminate it. The weathering flora often includes a small number of dominant species whose composition of this weathering flora varies with the food type and the storage conditions. Given the wide nutrients variety found in food and the microbial species diversity that contaminate them, a multitude of distinct chemical reactions can occur during spoilage (Benyelles & Bestaoui, 2018). According to Joffin (2010), the microorganisms' development in a food can have two harmful and varied actions:

• Affect the intrinsic quality of the food and therefore its commercial value (texture and appearance modification, the nutritional value alteration, the organoleptic qualities alteration, the packaging deterioration, etc.).

• Dangerous for health by being responsible for poisonings due to the formation of toxic substances (amines), or even infections or benign intestinal infections.

In addition, the oxidation phenomenon is particularly feared in terms of lipids and proteins because oxidative degradations lead to a decrease in the product quality, and the toxic substances appearance. Lipid oxidation is a complex natural phenomenon which affects unsaturated fatty acids and in particular polyunsaturated fatty acids, leads to the formation of primary products: peroxides, free radicals, conjugated dienes, very unstable and rapidly broken down into secondary

Table 2. Different categories of edible protein-based films

Type	Origin	Structure	Property	Application	Reference
Soy protein	Vegetal	Soy flour (56% protein and 34% carbohydrates), soy concentrate (more than 65% protein and 18% carbohydrates) and soy isolate (more than 90% protein and 2% carbohydrates)	Soft, clear, smooth, tackiness, cohesion, paste, emulsification, water and grease absorption, fiber formation and texturizing cap.	The meat industry (ground beef)	Chen et al. (2019); Dan Cristian et al. (2015); Denavi et al. (2009); Pedro Guerrero, O'Sullivan, Kerry, & de la Caba (2015); Ou, Kwok, & Kang (2004); Swain, Biswal, Nanda, & Nayak (2004)
Corn zein	Vegetal		Good film-forming properties, important barrier against oxygen, but the permeability to water vapor is high, breaking strength is similar to that of a synthetic film.	Candy and nuts, fruits and vegetables (tomatoes, apples, pears), Dairy Products (cheese, creamy Ricotta cheese).	Chen et al. (2019); Cho, Lee, & Rhee (2010); Lai & Padua (1997)
Wheat gluten	Vegetal	It contains gliadin and glutenin	Insoluble in water	Bakery products, cheese.	Ansorena, Zubeldia, & Marcovich (2016); Tanada-Palmu & Grosso (2003); Zubeldia, Ansorena, & Marcovich (2015)
Myofibrillar protein	Animal	Myosin and actin	Good mechanical, flexible and semi-transparent properties		Hamaguchi, WuYin, & Tanaka (2007); Hernandez-Izquierdo & Krochta (2008)
Milk protein	Animal	Casein and whey	Transparent, tasteless and flexible, better barrier against oxygen but their permeability to water vapor is low, biodegradability, high thermal stability. .	The meat industry (Fresh beef, Rainbow Trout Fillets)	Chen et al. (2019); Fabra, Talens, & Chiralt (2010); Khwaldia, Perez, Banon, Desobry, & Hardy (2004); Oses et al. (2009)
Gelatin	Animal/ vegetal	TYPE A (produced by hydrogen chloride) and TYPE B (produced by sodium hydroxide)	Great thickness and mechanical property, but low permeability to water vapor	The meat industry (Indian salmon fillets), vegetables and fruits (carrots, cherry, tomatoes, peppers, banana, eggplant, fresh-cut melons, strawberries, pineapple fruit, blueberry fruit)	Chen et al. (2019); P. Guerrero, Stefani, Ruseckaite, & de la Caba (2011); Liu, Nikoo, Boran, Zhou, & Regenstein (2015)

products (aldehydes, alcohols, ketones). Thus, during the oxidation reactions development the primary and secondary products of oxidation will appear successively. Lipid peroxidation leads to the degradation of the biochemical, organoleptic and nutritional properties of food (Guzun-Cojocaru, 2010). Although, the proteins oxidation is an important factor for industrialists as it has a significant impact on technological properties such as emulsification, gelation or the proteins extraction of interest. When free radicals react with proteins, more precisely with the radical grouping (side chain) of amino acids, carbonyl groups are formed. One of the most important changes in oxidized protein is the formation of carbonyls. These compounds cause a loss of protein functionality and the sensory and nutritional properties are modified (Kone, 2018).

Food spoilage can be considered an inevitable process depending on the food storage conditions such as the type of food, composition, formulation, packaging, storage temperature and relative humidity. Currently, the most promising methods in barrier technologies by enhancing the antimicrobial and antioxidant activity of edible films by adding non-toxic natural components with remarkable antibacterial and antioxidant properties (Alexa et al., 2018; Alvarez et al., 2013; Brasil et al., 2012; Costa et al., 2017; Gaikwad & Lee, 2017).

4.1. Antimicrobial agents

A real preservative is a component that is not normally consumed as a food that is incorporated into a food to increase its microbiological safety and stability. According to the antimicrobial preservative used, there are two modes of action, one bactericide: having the capacity to kill bacteria and the other, bacteriostatic: which inhibits the multiplication of bacteria without killing them. The site of action or the target of the preservative can be: the bacterial wall, membrane, protein synthesis, enzymes, DNA or bacterial RNA (Benyelles & Bestaoui, 2018).

The most common antimicrobial substances introduced in films are bactericins, enzymes, oils, plant extracts and preservatives, bacteriocins, ethylenediaminetetraacetic acid (EDTA), metal nanoparticles and essential oils (Alexa et al., 2018; Costa et al., 2017; Gaikwad & Lee, 2017). Table 3 shows the examples of certain antibacterial agents' application.

4.2. Antioxidant agents

An antioxidant is a substance that prevents the harmful effect of air O_2 on food quality. It is therefore a body with a particular electronic configuration. The latter allows it to play the role of hydrogen donor which oxidizes in place of fat. Such a structure is found especially in polyphenols to which the majority of synthetic antioxidants are attached. Unlike preservatives, antioxidants protect foodstuffs against aging they act on microorganisms and prevent alterations caused by oxygen such as rancidity of fats (Benyelles & Bestaoui, 2018). An antioxidant can be considered as a food additive which increases the shelf life of foods by protecting them from deterioration due to oxidation. There are two options for delaying the oxidation reaction, either intercepting the free radicals responsible for chain propagation, or avoiding the decomposition of hydroperoxides in free radicals, both modes of action provide the basis for classification of antioxidants in the form primary or secondary (Nimse & Pal, 2015). Synthetic antioxidants include sulfur dioxide and its mineral combinations, propyl gallate, octyl gallate, butylhydroxyanisole (BHA), butylhydroxytoluene (BHT) and tert-butylhydroquinone (TBHQ) (Just, Nyunga, Lelong, & Wallaert, 2005). Nevertheless, synthetic antioxidants are less and less used in food packaging because of their safety concerns, than natural antioxidants such as ascorbic acid, α-tocopherol, ferulic acid, coumarin, EO, phenolic compounds and plant extracts (Benbettaïeb et al., 2016; Caillet & Lacroix, 2007; Jiménez, Fabra, Talens, & Chiralt, 2013; Shokri & Ehsani, 2017). The most additive antioxidants in the food coating are shown in Table 4.

Table 3. Antimicrobial agent applications in edible films

Antimicrobial Agents		Edible films	Affected microorganisms	Effect on film performance	References
Bacteriocins	Nisin	Whey protein isolate, soy protein	*L. monocytogenes, P. aeruginosa, Yarrowia lipolytica, P. commune, P. chrysogenum*	The strength was increased and the permeability was decreased	Gadang, Hettiarachchy, Johnson, & Owens (2008); Sivarooban, Hettiarachchy, & Johnson (2008)
	Natamycin	Wheat gluten and MC	*A. niger* and *P. roquefortii*	/	Ture, Eroglu, Ozen, & Soyer (2011)
EDTA		Whey protein isolate, soy protein, Corn Zein	*L. monocytogenes, E. coli, S.* Typhimurium, and *S. enteritidis*	A weak effect on the mechanical properties.	Gadang et al. (2008); Hoffman, Han, & Dawson (2001); Sivarooban et al. (2008)
Acidulant agents	Sodium lactate, potassium sorbate, and citric, acetic, malic, lactic, tartaric, sorbic and paminobenzoicacids	Sodium caseinate, whey protein	*L. monocytogenes, E. coli, S. gaminara,* and *S.* Typhimurium	Affects water vapor permeability and stretchability too, leads to increased glass transition temperature.	Kristo, Koutsoumanis, & Biliaderis (2008); Pintado, Ferreira, & Sousa (2009)
Antimicrobial enzymes	Lysozyme, catechin and gallic acid	Zein–wax	*L. monocytogenes*	/	Ünalan, Arcan, Korel, & Yemenicioğlu (2013) İlke et al., 2013.
	Lacto Per Oxidase System and lysozyme	Sodium caseinate, whey protein	*S. putrefaciens, P. fluorescens, L. monocytogenes, B. subtilis, E. coli,* and *S. aureus*	The film structure and integrity were weakened.	Mendes de Souza, Fernández, López-Carballo, Gavara, & Hernández-Muñoz (2010); Shokri & Ehsani (2017)
NP	Na^+ montmorillonite, halloysite and Nanomer	Fenugreek seed gum /clay nanocomposite	*S. aureus, L. monocytogenes, E. coli* O157: H7, *B. cereus*	Improved oxygen barrier and thermal properties, higher tensile strength and decrease elongation at break.	Memiş, Tornuk, Bozkurt, & Durak (2017)
	Silver nanoparticles (AgNP)	Gelatin	Foodborne pathogens	The barrier and mechanical properties were enhanced, but there might be potential toxicity.	Kanmani & Lim (2013)
	ZnO nanoparticles and 3-methacryloxypropyltrimethoxysilane. .	Polylactide	*S.* Typhimurium, *L. monocytogenes.*	The glass transition, crystallization temperatures of composites were improved.	Arfat et al., (2014)
EO	Cinnamon	Fish skin gelatin, Polylactic acid, Sodium alginate / CMC	*E. coli, S. aureus, A. niger, R. oryzae, P. varioti, L. monocytogenes* and *S.* Typhimurium	Reducing tensile strength, tensile modulus, elongation at break and water content on the other hand increases water vapor and oxygen permeability, thickness.	Ahmed, Mulla, & Arfat (2016); Han, Yu, & Wang (2018); Wu, Sun, Guo, Ge, & Zhang (2017)
	Castor	Sodium alginate	A significant inhibitory effect of films against Gram-positive bacteria while no effect has been observed for Gram-negative bacteria.	Thermal stability was improved, the water vapor permeability was reduced.	Abdel Aziz, Salama, & Sabaa (2018)
	R. officinalis L, *A. herba alba* Asso, *O. basilicum* L and *M. pulegium* L	Fish protein and fish skin gelatin isolate, Sodium alginate	Food-borne spoilage, *S. aureus, E. coli, S. enterica, E. faecium, K. pneumoniae* and *E. faecalis*	Slightly improves thermal and barrier properties and elongation at break, in gully, reducing tensile strength.	Arfat et al. (2014); Mahcene, Khelil, Hasni, Akman, et al. (2020)

EDTA: Ethylene diamine tetra acetic acid; NP: Nanoparticle; EO: Essential oil; CMC: Carboxymethyl cellulose.

Table 4. Antioxidant agent applications in edible films

Antioxidant agents	Edible films	Results	References
Catechin and gallic acid	Zein–wax	Prevent oxidative changes in cheese	Ünalan et al. (2013)
Ethanolic extract from coconut husk	Tilapia and squid skin gelatins	Low peroxide and thiobarbituric acid reactive substances (TBARS), total volatile base (TVB).	Nagarajan, Benjakul, Prodpran, & Songtipya (2015)
R. officinalis L, *A. herba alba* Asso, *O. basilicum* L and *M. pulegium* L EO	Sodium alginate	The anti-radical DPPH capacity between 4.57% and 23.09%.	Mahcene, Khelil, Hasni, Akman, et al. (2020)
Red grape extracts	Soy protein	Significant increase in the scavenging power of the free radical DPPH and in the reducing power of iron for the activated film.	Ciannamea, Stefani, & Ruseckaite (2016)
Green tea extract	Silver carp skin gelatin	Enhancing the total phenolic content, DPPH radical scavenging activity and reducing power.	Wu et al. (2013)
T. kotschyanus EO	Starch-chitosan	Antioxidant property significantly increased with the incorporation of EO ($p < 0.05$).	Mehdizadeh, Tajik, Razavi Rohani, & Oromiehie (2012)
O. heracleoticum L and T. vulgaris L EO	Soy protein	Higher antioxidant activity by edible films was determined with a 2,2'-diphenyl-2-picrylhydrazyl radical-scavenging assay.	Kodal Coskun, Calikoglu, Karagöz Emiroglu, & Candogan (2014)
Ginger EO	Starch	The best antioxidant occurs in 3% essential oil with 31.50 percent reduction of DPPH.	Miksusanti, Herlina, & Masril (2013)
Zataria multiflora Boiss EO	Zein	Improvement were obtained for antioxidant activity of films.	Moradi, Tajik, Razavi Rohani, & Mahmoudian (2016)
Lysozyme, albumin proteins (CPAE) and disodium EDTA.	Zein	The incorporation of lysozyme did not contribute to the soluble free radical scavenging activity of the zein films. However, the incorporation of lysozyme in combination with CPAE increased the soluble and immobilized free radical scavenging activity of zein films by 17% to 25% and nearly 84%, respectively.	Güçbilmez, Yemenicioğlu, & Arslanoğlu (2007)
Cinnamon, guarana, rosemary and boldo-do-chile ethanolic extracts	Gelatin-chitosan	The films show significant antioxidant activity in the TEAC test.	Bonilla & Sobral (2016)
Maqui berry *(Aristotelia chilensis*)	Chitosan	The film shows greater antioxidant power at all concentrations (0.5 and 1%) and with the 38 methods tested: DPPH radical scavenging capacity test, ferrous chelation capacity (FIC) and ferric reducing capacity (FRAP).	Genskowsky et al. (2015)

5. Edible Film Applications

5.1. Fresh produce

Since most fresh products such as fruits and vegetables contain a lot of water. However, the conservation of their water is essential. Stored fruits and vegetables can be coated with paraffins and natural waxes. Edible films tend to act as a protective layer around the surface of fresh produce and delay spoilage by reducing respiration (Aydin et al., 2017). According to Dhaka & Upadhyay (2018), common applications of the edible coating include several flavor purposes, controlling mass transfer, reducing oxidation and processing, and improving gloss and surface textural properties of fresh produce. Table 5 groups together some results of the use of edible films to preserve fresh products.

5.1. Meat, fish, poultry and meat products

Meat is a food with a tissue structure, it is rich in nutrients and water. Meat and meat products are highly susceptible to contamination by microorganisms and to the oxidation phenomenon (Adelakun, Oyelade, & Olanipekun, 2016; Ahmed, Almusallam, Al-Salman, AbdulRahman, & Al-Salem, 2013; Pal & Devrani, 2018). The oxymyoglobin red color of meat can be affected by a high concentration of oxygen on the surface. This can be attained by using packaging materials with high oxygen permeability or modified atmosphere packaging with high oxygen permeability. However, high oxygen levels cause gram negative bacteria to grow rapidly on the surface of fresh meat (Chen et al., 2019). The results obtained by some previous work on the application of edible coating systems to preserve meats, fish, poultry and meat products are shown in Table 5.

5.2. Dairy products

Cheese is the most varied group of all foodstuffs. Its short shelf life of cheese is associated with the uncontrolled growth of microorganisms on their surface. The other forms of spoilage of dairy products can be evidenced by light induced oxidation and the presence of moisture accelerates namely, loss of nutrients, loss of color and formation of bad taste (Chen et al., 2019; Fox, 1993). Therefore, the coating of dairy products with edible films can reduce the degradation thereof. Various researches have been carried out in order to use biodegradable films to preserve cheese. The results obtained are shown in Table 5.

Table 5. Applications of edible films for food preservation

Food		Edible film	Additive	Results	Reference
Fruits and vegetables	Broccoli	Chitosan		Reduction in the total number of mesophilic bacteria, total coliforms and psychrotrophs during storage time.	Moreira, Roura, & Ponce (2011)
			EO of *M. alternifolia; R. officinalis ; S. aromaticum ; C, limonum ; O, vulgare ; C, officinalis ; A, ferox*	Inhibits the growth of mesophilic and psychro-trophic bacteria, and also controlled the survival of *E. coli* and *L. monocytogenes*.	Alvarez et al. (2013)
	Papaya	Polysaccharide		Extension of its shelf life up to 15 days at 4 °C.	Brasil et al. (2012)
	Pineapple	Caseinates and Chitosan		Extension of shelf life.	Talens, Perez-Masia, Fabra, Vargas, & Chiralt (2012)
	Tomato	Aloe vera		Delays ripening and extends shelf life up to 39 days.	Athmaselvi et al. (2013)
	Carrot	Cactus mucilage	Soybean and olive oil	The pH, total soluble solids, ascorbic acid and microbial number are maintained during the storage period. The coating allowed a better visual quality.	Oluwaseun, Kayode, Bolajoko, & Bunmi (2013)
Meats and fish	Buffalo meat patties	sodium alginate	sodium ascorbate and citric acid	The overall values of the shear force, thiobarbituric acid tyrosine as well as the number of psychrophiles and yeasts and molds decreased by the coating treatment. Coating at the 2% level improved the overall appearance and color, juiciness, flavor, texture and overall palatability of the product.	Chidanandaiah, Keshri, & Sanyal (2009)
	Bream (*Megalobrama amblycephala*)		Vitamin C and tea polyphenols	The coating treatments mainly reduced chemical deterioration, reflected by volatile basic nitrogen, pH and thiobarbituric acid, delayed water loss and increased the overall sensory quality of fish compared to uncoated one.	Song, Liu, Shen, You, & Luo (2011)
	Ground beef patty	Soy protein	Thyme and oregano EO	Reduction in the number of *Pseudomonas* spp. and coliform bacteria during refrigerated storage	Emiroğlu, Yemiş, Coşkun, & Candoğan (2010)
				No negative effect on hedonic attributes	Pedro Guerrero et al. (2015)
	Smoked sea bass fillets (*Dicentrarchuslabrax*)	Chitosan and alginate		The alginate protected the fillets against oxidation but did not inhibit bacterial growth. Chitosan causes complete inhibition of the growth of mesophilic, psychrophilic and anaerobic bacteria.	Martinez, Salmeron, Epelde, Vicente, & de Vega (2018)
	Fish fillet	Whey protein	Cinnamon EO	The shelf life can be extended.	Bahram et al. (2016)
Cheese	Mongolian cheese	starch–chitosan	Hydrophilic glycerol and hydrophobic perilla oil	Retarded the weight loss during 30 days of storage	Mei et al. (2013)
	Mozzarella cheese	Sodium alginate	Potassium sorbate	Limits the development of Enterobacteriaceae and *Pseudomonas* spp.	Lucera et al. (2014)
	Home-made cheese		*R. officinalis, O. basilicum, A. herba alba* and *M. pulegium* EO	Moderate stability in terms of oxidative stabilities of proteins and lipids during storage. In addition, poor microbial growth (total aerobic mesophilic flora, yeasts and fecal coliforms) was observed in cheese samples coated with biofilm, also, the growth of *Staphylococci, Salmonella* and molds for all types of cheese were completely inhibited	Mahcene, Khelil, Hasni, Bozkurt, et al. (2020)
	Semi-hard cheese	Galactomannan	Corn oil	Reduces O_2 consumption and CO_2 production rates	Cerqueira et al. (2009)
	Semi-hard kashar cheese	Whey isolate	Thyme and clove EO	Levels of *E. coli* O157: H7, *L. monocytogenes* and *S. aureus* decreased	Kavas, Kavas, & Saygili (2015)
	White cheese		Oregano EO	Delay lipid oxidation	Gurdian et al. (2017)
	Cheddar cheese	Starch	Carvacrol, linalool and thymol	Effective inhibition of *S. aureus*	Kuorwel, Cran, Sonneveld, Miltz, & Bigger (2011)
	Feta cheese (curd cheese)	Zein	*Z. multiflora* Boiss EO	Decreased number of *S. enteritidis, L. monocytogenes, E. coli* and *S. aureus*	Ghasemi, Javadi, Moradi, & Khosravi-Darani (2015)
Bakery products and candies	Dough bread	Modified corn starch	Tomato powder and ascorbic acid	Contributed to the expansion of bread. The browning index of the crust has decreased	Galvao, Zambelli, Araujo, & Bastos (2018)
	Crackers	Starch, methylcellulose and soybean oil		Longer shelf life and higher moisture absorption and resistance to water vapor transmission	Bravin et al. (2006)
	Wheat and soy cereal bars	Vegetal oils		Thus improving the lightness and general acceptance of the product	Aramouni & Abu-Ghoush (2011)
	Rice fortified with vitamins and minerals	Rosin-zein		Prevent loss of vitamins and minerals when washing in cold water	Suput et al. (2015)

EO: Essential oil

5.3. Bakery products and candies

Cookies and cereals should have a crunchy consistency. Loss of brittleness and acquiring a smooth structure occurs with an increase in the water content. Unbaked or pre-cooked dough products such as pizza or short-crust pasta have improved microwave properties when the products are provided with a moisture barrier layer (Maftoonazad & Badii, 2009). Edible coating for bakery products and candies is optimal when the pressure is 2 bar and the film thickness is 30 µm (Bravin, Peressini, & Sensidoni, 2006). The application of edible packaging to preserve the characteristics of bakery products and candies is the subject of several studies. Table 4 shows some of the results obtained.

6. Limitations Related to Edible Films

Edible films show many benefits such as affordability, ease of application and use of natural ingredients, etc. However, there are several weaknesses that draw the attention of scientists and developers, which are tried to be overcome by several ways such as development of edible composite films and use of reinforcement agents. The main drawbacks associated with the different types of edible films are mentioned as (Campos, Gerschenson, & Flores, 2011; Dhaka & Upadhyay, 2018; Okcu, Yavuz, & Kerse, 2018; Suput, Lazic, Popovic, & Hromis, 2015):

- Based on protein: low water resistance and physical properties such as tensile strength, elongation at break, puncture resistance. To form an edible protein film, the protein must be denatured by heat, acid, alkali and/or solvent.

Based on polysaccharides: low barrier against moisture permeability due to the hydrophilic nature of the constituents, thus their mechanical properties are moderate.

- Based on lipids: poor oxygen barrier property which makes food predisposed to deterioration by oxidation. Also, they have poor mechanical properties and an oily appearance in some products that affect the foods sensory properties.

7. Conclusions

Edible films are rapidly emerging as alternatives to synthetic packaging materials. Their biodegradability, selective barrier properties, biocompatibility and edibility in addition to being non-toxic and non-polluting are some advantages over plastic packaging. They have been shown to be effective in increasing the microbial and oxidative stability of fresh or modified food products and therefore prolonging their shelf life. However, there has been increasing interest in developing the preservative properties of packaging materials. Edible films activated after their reinforcement by natural antioxidant and antimicrobial agents which can effectively inhibit or retard the growth of microorganisms and oxidation thus ensuring food safety and prolonging its shelf life, those selected according to food and requirements storage. However, researching the relationship between film efficiency and its structure and components will contribute a lot to knowledge of film modification methods and schemes, so that films suitable for food packaging with better properties are produced.

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