# Development of biodegradable packaging materials from marine and agro-waste

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## Introduction

Food packaging is an essential component of the food supply chain and is becoming a pivotal element of the final preparation process in food industries. Food packaging also plays an imperative role in society, protecting food and food products from potential damage and degradation while ensuring safety and hygiene, and actively reducing food waste. It is estimated that more than 30% of food produced is deposited in landfills due to spoilage during transportation and/or harvesting practices (Aguirre-Joya et al., 2018). Therefore, the application of adequate food packaging can assist in the reduction and prevention of the generation of food waste (Aguirre-Joya et al., 2018). The appropriate selection of food packaging should also ensure no negative alterations in food quality (i.e. colour, taste), microorganism development, lipid oxidation or degradation of nutrients in the food (Umaraw et al., 2020).

Conventional packaging is commonly a one-time use item that is discarded upon reaching the consumer or after using the packed content. As such, conventional packaging poses a tremendous environmental burden despite relatively high recycling rates (Jeevahan & Chandrasekaran, 2019). One of the main issues is the non-sustainable nature of plastics, which are commonly derived from petroleum such as polyethylene, polypropylene, and polyethylene terephthalate are widely used due to their relatively easy shape-forming properties and lower weights than other materials (Ahmadi, et al., 2020). Moreover, these materials are considered as not 'environmentally friendly' with the majority of them being non-renewable and also non-biodegradable, which subsequently end up in the landfills or oceans. Additionally, the use of these materials for food packaging has other, secondary negative environmental impacts, such as environmental pollution via generation of $CO_2$ and emission of other toxicants during their incineration, reliance on non-renewable petroleum reserves, and potential for harmful interactions between potential recycled/reused plastics and food (Aguirre-Joya et al., 2018).

Concurrently with the increased environmental concern regarding the growing rate of waste from packaging materials, current consumer demands and needs are directed towards more natural, high-quality, convenient and safer foods, posing a significant challenge to the food industry. There is an increasing demand for food packaging that does not increase pollution, and for products that are efficiently made by sustainable processes. Consequently, this has initiated an awareness and rise in research and industry focus on the development of sustainable, biodegradable, and edible materials that can improve food safety and increase food quality. Starches, cellulose derivatives, chitosan/chitin, gums, animal or plant-based proteins, and lipids can be incorporated into edible films to prolong shelf life. Such polymers deliver marketable advantages, such as biocompatibility, moisture and/or gas barrier properties, non-toxicity, and non-polluting characteristics (Mellinas et al., 2016). In this context, active, biodegradable and edible packaging materials are considered as one of the top priorities in the food industry due to the increased need for alternative packaging materials that are renewable, recyclable, easily degradable and require minimal or no need of disposal (Jeevahan & Chandrasekaran, 2019; Jeevahan et al., 2018).

**Edible packaging**

Edible packaging is regarded as a sustainable and biodegradable alternative in active food packaging field and provides food-quality optimisation compared to the conventional packaging. The usefulness of edible packaging is seen in its capacity to maintain food quality, extend shelf life, reduce waste, and to contribute to the economic efficiency of packaging materials. The development and application of edible films are among the most promising fields in food science due to their versatility, potential for being made from a variety of materials, and as carriers of different active substances such as antioxidant and/or antimicrobial agents. This has resulted in a significant increase in research activities in this area over the last decade, with several issues identified for consideration before adequate and safe industrial scale-up of edible food packaging (Aguirre-Joya et al., 2018; Restrepo et al., 2018). The materials of the food packaging are derived from edible ingredients such as natural polymers that can directly be consumed by humans without any potential health risk. These materials can be transformed into different forms of films and coatings without specific differences in their material composition but rather by changes in their thicknesses. Films are generally used in the production of wraps, pouches, bags, capsules, and casings, while coatings are applied directly on the food surface. In contrast to the films, the coatings are considered an integral part of the food product, and they are typically designed not to be removed from the food item (Aguirre-Joya et al., 2018). Therefore, proper selection of edible packaging components mainly depends on the food product required to be packed, and the composition of the material that the edible packaging is developed from, including the method of processing. Moreover, the packaging should have sensory compatibility with the packed food (Restrepo et al., 2018).

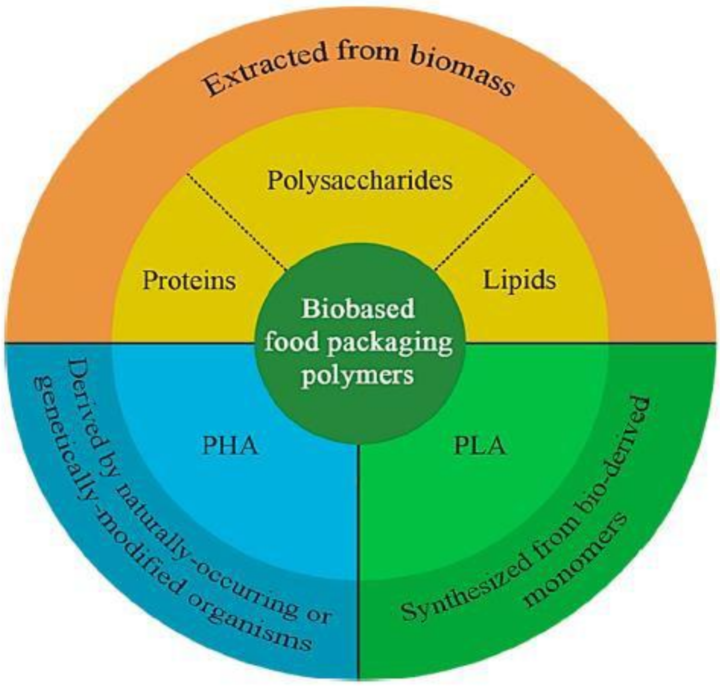


**Fig. 1. Biobased materials for food packaging**
(PHA=PolyHydroxyAlkanoate; PLA=PolyLactic Acid)

**Materials for edible packaging**

There is ongoing research into the possibility of replacing synthetic and petroleum-based packaging with biologically-based, biodegradable materials. The use of bioengineered polymer resources for food packaging is an attractive packaging solution for many reasons; however, it is also a major food technology challenge (Ahmadi et al., 2020).

Bio-based and biodegradable materials can be categorised into three categories based on the sources from which they originate (Fig. 1) as follows:

- ➢ Biomass/natural sources (proteins, polysaccharides, and lipids)
- ➢ Materials produced by microorganisms
- ➢ Materials produced from bio-based monomers

Edible packaging materials are a subgroup of bio-based and biodegradable materials and have been extensively studied as an alternative to the traditional food packaging from the aspect of their film-formation properties. Biopolymers used as edible materials are classified as:

- Polysaccharides
- Proteins (animal- or plant-based)
- Lipids
- Composites

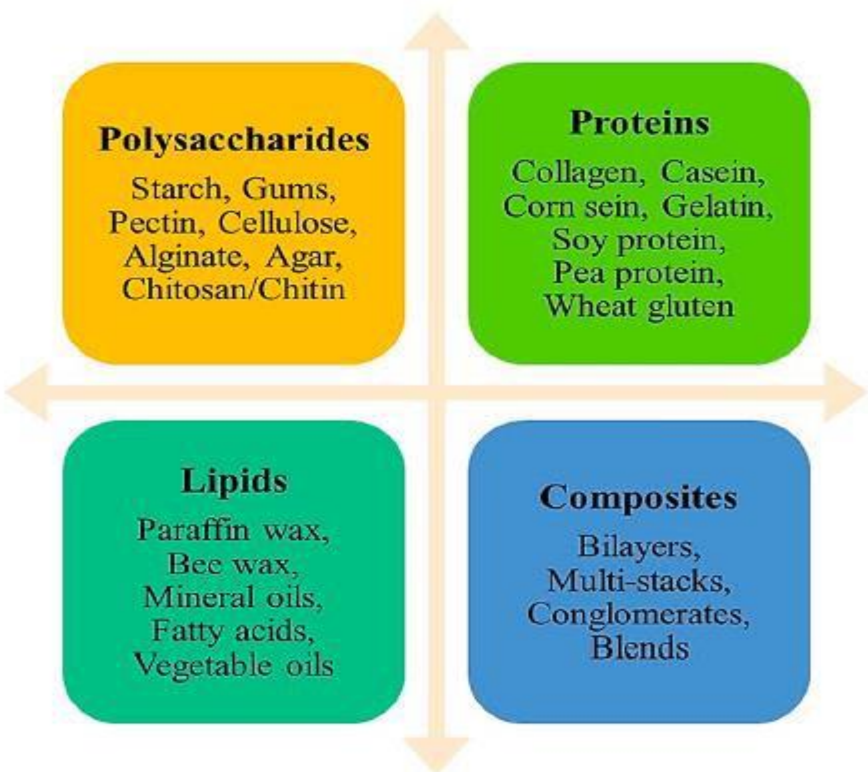


**Fig. 2. Classification of edible materials**

These edible materials can be used in various food technology applications alone or in combination with other components (Fig. 2). The term hydrocolloids are usually used as a mutual term for polysaccharides and proteins. Hydrocolloids possess long-chain hydrophilic polymers that form viscous dispersions or gels when dispersed in water (Jeevahan & Chandrasekaran, 2019).

Edible films and coatings vary in their nature and origin with a number of different examples used such as chitosan coating (Alvarez et al., 2013), tomato-based (Du et al., 2008), quinoa protein/chitosan edible films (Robledo et al., 2018), apple-based (Ravishankar et al., 2012), banana starch (Pinzon et al., 2020), Aloe Vera, carrot film, rice, maize, potato and hibiscus films among others (Fangfang et al., 2020).

**Characteristics of edible packaging: advantages and limitations**

Edible materials have many advantages over synthetic materials. Edible packaging can function as a replacement and potential fortification of the layers at the outer surface of packaged products to prevent loss of moisture, aromas and ingredients out and between the foods, while at the same time, facilitating controlled exchange of essential gases involved in food product respiration (carbon dioxide, oxygen, and ethylene) (Galus & Kadzi´nska, 2019). Edible packaging can also enhance the organoleptic properties of packaged foods, providing various flavourings and colourings as well as tailoring surface properties (i.e. hydrophobicity, hydrophilicity). Additionally, these can serve as a carrier of functional components with potentially added health or well-being benefits (Pooja Saklani et al., 2019). The hydrophilic nature of polysaccharides and proteins contribute to lower moisture resistance and barrier properties in comparison to lipids (Arnon-Rips & Poverenov, 2016). Polysaccharides are also suitable oxygen barriers while proteins show relatively good mechanical strength and can be used on fruits and vegetables to prevent damages during their transportation. In contrast, lipids show low water vapour permeability and relatively good moisture barrier properties. Lipid-based edible packaging is often opaque, waxy tasting, slippery, and usually preserves the colour, flavour, sweetener and salt concentrations (Galus & Kadzi ´nska, 2015). However, lipids have poor mechanical and optical properties, as they are relatively thick and easily breakable. In addition, in some cases, there is poor adhesion of these materials to hydrophilic food surfaces (Aguirre-Joya et al., 2018).

The composite edible packaging is proposed to improve the required properties depending on the final application to different food products. In most cases, the composite films consist of a protein, lipid layer and hydrocolloid components supported by a polysaccharide, or lipid material dispersed in a protein matrix or polysaccharide matrix (Aguirre- Joya et al., 2018). In these types of edible packaging, the combination of at least two constituents are proposed where the weakness of individual substance is compensated by adding the other component. For instance, the water vapour permeability of polysaccharides and proteins can be improved by adding lipids, forming edible composite that possesses both hydrophilic and hydrophobic properties. In addition, the mechanical strength of lipids is improved by adding proteins or polysaccharides, and even the overall mass transfer in edible material can be adjusted (Jeevahan & Chandrasekaran, 2019). In general, innovation in the edible packaging sector has the potential to become an everyday part of consumers' life. However, edible packaging will likely not solve the problem of plastic waste pollution, but, it can make a meaningful contribution.


**3.1. Barrier functions of edible packaging**

The moisture and oil absorption, oxygen transfer, flavour and odour change, or the migration of packaging components into the food are primarily responsible for the food quality (Dubey & Dubey, 2020). These characteristics also contribute to the mass transfer phenomena which occurs between foods (including some ingredients in the food product) and packaging materials, or between food and the environment. In the case of edible films and coatings, it is proposed that these products may prevent migration phenomena and contribute to better quality performance of the packed food products (Zhang et al., 2020). All barrier or transport properties of the edible films and coatings are also affected by the material composition and environmental conditions (relative humidity, temperature, pressure) at which the food products are processed and stored (Siracusa et al., 2020).

**3.2. Deposition processes for edible packaging**

Edible materials are usually applied on food by immersion, spraying and coating or by being formed prior to a film and used as a food wrap. The difference between an edible film and coating is that coatings are applied in liquid forms, while films are obtained as a solid sheet (i.e. laminates, multilayered films) and then applied to the food (Aguirre- Joya et al., 2018). Films are usually prepared by dissolving the edible material in water, alcohol, or a mixture of solvents. To enhance the flexibility and durability of these materials, additives such as plasticisers are incorporated in matrix material (Murrieta-Martínez et al., 2019). In addition, some additives with unique functionality could be added such as antimicrobial agents, colours, and flavouring, depending on the final application of the edible material (Bilal, et al., 2020). The type of edible packaging solution and application method mainly depends on the surface properties of the food product that should be covered (wettability, contact angle, surface tension (Aguirre-Joya et al., 2018).

Edible coatings are applied directly onto the food surface from liquid suspension, emulsion or powder form. This application of the edible coating solution on food is followed by an adhesion process requiring diffusion between both the coating solution and the surface area of the food product (Senturk & Müller, 2018). Some methods for application of edible coatings on food products are dipping, spraying, brushing, fluidised bed processing, and the panning method (Suhag, et al., 2020).

For the production of edible films, in general, two types of processes exist: wet and dry processes. The wet process (casting) requires solvents for the solution and dispersion of the polymer onto a flat surface, followed by drying under controlled conditions which results in the formation of film (Suhag et al., 2020). Since the final product should be edible and biodegradable, only ethanol and water or their combination are adequate solvents. The production of edible films by dry methods includes extrusion, injection, blow moulding, and heat-pressing processes. In general, dry processing utilises thermoplastic materials that can be processed into films by applying various thermal-mechanical processing techniques. This process is advantageous compared to wet process due to the absence of solvents, easy handling of high viscous polymers and a broad range of processing techniques. In order to improve the film performance, in most cases, the method of lamination is used (Janjarasskul & Krochta, 2010).

The multilayered structures and the combination of characteristics of various ingredients into a sheet is also a preferred packaging option due to many advantages such as higher toughness and tensile strength compared to the individual ingredients (Suhag et al., 2020). Numeorus studies have explained the utilisation of various deposition methods for coating applications for food products to increase their shelf life and enhance their quality and safety as well (Suhag et al., 2020).

## 4. Edible packaging as a carrier for functional bioactive compounds

Active and smart packaging has been used worldwide, mostly in the United States, Australia and Japan, while in Europe it was introduced after European Union (EU) legislation changes (Regulation EC, 1935/ 2004). The EU definition of active packaging (as defined in the European regulation [EC] No. 450/2009) states that active packaging systems are designed to "deliberately incorporate components that would release or absorb substances into or from the packaged food or the environment surrounding the food." In this way, they "intend to extend the shelf-life or to maintain or improve the condition of packaged food" (Yildirim et al., 2018). One of the significant emerging functions of edible packaging materials is their use as a matrix and carrier of different functional additives that can provide additional nutritive and health benefits to the packaged food (Broumand et al., 2011). Usually, different antimicrobial and antioxidant substances, prebiotics or other nutrients can be added to edible matrices to extend shelf life and/or increase the nutritional value of the final packaged food (Odila Pereira et al., 2019). Several different substances could be incorporated into edible films to enhance structural, mechanical and handling properties or to provide active functions to the coating (Yousuf & Qadri, 2020).

### 4.1. Nutraceuticals in edible packaging

Nutraceuticals are compounds that are usually derived from food sources and can provide health benefits (Nasri, et al., 2014). Their incorporation into the food coatings can potentially compensate for the loss of nutrients that usually occur during food processing, or increase the nutrient composition of the newly coated food products. Edible matrices also appear to be suitable carrier materials for nutraceuticals as in some cases, direct use of nutraceuticals on food is not recommended due to their fast degradation or potential for production of undesired reactions in foods and consumers if taken in large quantities (Arnon-Rips & Poverenov, 2016). The main influence of the nutraceuticals besides being a source of nutrients and energy is to provide potential beneficial health effects (Khorasani, et al., 2018). In the literature, there are some nutraceutical compounds that have a positive influence on the human health, such as ascorbic acid (antioxidant), pectin (cardiovascular support), casein phosphopeptides (anti-atherosclerotic), omega fatty acids (anti-inflammatory), polyphenols (antioxidant and many other benefits), capsaicin (anticarcinogenic), betacarotene (enhance the immune system, protect from age-related macular degeneration) to name a few (Khorasani et al., 2018).

### 4.2. Antioxidants and antimicrobials in edible packaging

Antioxidants can be added to edible materials to delay the rate of oxidation reactions and to increase food safety and quality (Munialo, et al., 2019). These compounds can suppress the activity of free radicals via several different pathways such as acting as scavengers of free radicals (i.e. glutathione), chain-breaking antioxidants neutralising the intermediate peroxyl radicals (i.e. ascorbic acid) and preventative antioxidants that can bind to certain metal cations (i.e. albumin). Therefore, with the use of antioxidants, there is a great potential the food products to be protected from damaging oxidative reactions, such as colour changes (i.e. enzymatic oxidation), altered flavours and odours (i.e. oxidative rancidity), as well as reduce structural modifications (i.e. softening) with time and potential nutritional losses (Arnon-Rips & Poverenov, 2016). Examples of 'naturalorigin' antioxidants include plant extracts, essential oils, α-tocopherol, ascorbic, and citric acid, bee pollen, propolis and are all widely used individually or combined (Benbettaïeb et al., 2019). Plant extracts are often used in food packaging (Kumar et al., 2019), as among which pomegranate peel/dried extract (Kumar et al., 2019), and quince seed mucilage (Jouki, et al., 2014), grape seed extract (Xiong, et al., 2020), green tea extract (Sabaghi et al., 2015), mint extracts (Raghav & Saini, 2018), black chokeberry extract (Kim, Baek, & Song, 2018) are on the top of the list. Recently, essential oils extracted from plants have been added as ingredients to the edible film formulations. These extracts have several bioactive compounds that can provide films with specific characteristics, but the most important is to be safe and edible. Such types of active packaging effectively extend food shelf life and contribute to the quality and safety of the packed content. Use of essential oils as substitutes for chemical antimicrobial agents can enhance the microbiological shelf-life of food products. Several studies have indicated beneficial antimicrobial effects against different types of microorganisms including human pathogens. The incorporation of these natural compounds into the product formulation or packaging materials not only inhibit fungal growth, but can also enhance oxidation stability. Along with a beneficial activity, essential oils may also affect the food organoleptic features and potentially act as flavour component (Pavli et al., 2019).

Edible films and coatings can also be an efficient carrier of live microorganisms. Namely, incorporation of probiotics in the edible material, such as Lactic acid bacteria (LAB) or yeasts like Saccharomyces cerevisiae var. boulardii, Debaryomyces hansenii, Torulaspora delbrueckii, Kluyveromyces lactis, Yarrowia lipolytica, S. cerevisiae, Kluyveromyces marxianus, or Kluyveromyces lodderae can result in positive effects during processing and storage of food products. Different methods, such as microencapsulation or spray drying methods are used to incorporate microorganisms into these edible films and coatings that affect the viability and effective delivery of the microorganism within the polymer matrix (Vasile, 2018). Different studies have revealed that incorporation of microorganisms with antimicrobial properties limits the growth of pathogens when used for food packaging (Siracusa et al., 2020).

Antifungal (Robledo et al., 2018), antiviral (Falc´o et al., 2019), and antimicrobial agents (Salvia-Trujillo, et al., 2015), enhance the shelf life of foods and can be derived from natural or synthetic substances (Sharma et al., 2020). According to many of these studies, essential and cold-pressed oils exhibited selective antibacterial and antifungal effect against food spoilage fungi once added in the edible film: Fusarium graminearum, Penicillium corylophilum, Aspergillus brasiliensis; and some potential pathogenic food bacteria, such as Staphylococcus aureus, Escherichia coli, Listeria monocytogenes or against Pseudomonas aeruginosa (Arancibia et al., 2014). Namely, antifungal and antiviral effects of green tea extract were confirmed on nuts and berries, respectively, against some foodborne pathogens like human noroviruses, hepatitis A virus (Randazzo et al., 2018).

The most widely used antimicrobial substances include organic acids (acetic, benzoic, citric, fumaric, lactic, malic, propionic, sorbic, succinic, and tartaric acid), polypeptides (lysozyme, peroxidase, lactoferrin, nisin), essential oils (oregano, lemongrass, cinnamon, tea tree, clove, pimento, thyme, calendula, basil, rosemary, bergamot, sage, garlic, etc.) (Xiong et al., 2020). Antimicrobial food nanocarriers are also suitable for controlling spoilage and growth of pathogenic microorganisms in foodstuff (Arnon-Rips & Poverenov, 2016). The (nano)carriers of antimicrobials are usually reported as nanoemulsions, nanoliposomes, nanoparticles, and nanofibers, and their incorporation into edible matrices effectively controls and maintains the function of the antimicrobials by protecting their fast diffusion into the food products (Arnon-Rips & Poverenov, 2016). The incorporation of active compounds into edibles improved drastically with the development of novel nanotechnologies, where the actives can be in micro- and nano-dimensions and different shapes. For instance, the actives are being incorporated in matrices as (nano)-liposomes, nanoemulsions, nanoparticles, nanofibers or as layerby-layer technique (Aguirre-Joya et al., 2018).

Due to their small dimensions, nanomaterials are able to attach to many biological molecules with greater efficiency. The antimicrobial activity of nanoparticles, in general, is described as: directly interactions with microbial cells and interruption of the transmembrane electron transfer, disrupting/penetrating the cell envelope, oxidizing cell components, producing secondary products as reactive oxygen species or dissolved heavy metal ions (Vasile, 2018). Nanoparticles like TiO2 show efficacy on bactericidal and fungicidal effect against Salmonella choleraesius, Vibrio parahaemoliticus, Staphylococus aureus, Diaporthe actinide, Penicilinum expansum. In addition, ZnO is efficient both against Gram-positive and Gram-negative bacteria while nano-ZnO coated films exhibit antimicrobial effects against L. Monocytes and S. Enteritis. The antibacterial activity of Ag ion is reduced by protein-rich food and can bind to cysteine, methionine, lysine, and arginine. Its antimicrobial activity is explained by adhesion to the cell surface, degrading lipopolysaccharides, damaging the membranes and increasing permeability. The Ag ions can be released to prevent food spoilage as they are effective against bacteria like, E. Coli, Enterococcus faecalis, Staphylococcus aureus, Epidermidis, Vibrio cholera, Pseudomonas aeruginosa, Bacillus anthracis, Proteus mirabilis, Salmonella enterica typhmurium, Listeria monocytogenes, and Klebsiella pneumoniae (Kumar et al., 2020).

**4.3. Other additives in edible packaging**

The function of other additives in edible materials are relatively known but have shown to have good processing or desired final properties of the food products. Some of these materials include plasticisers, emulsifiers and texture enhancers (Aguirre-Joya et al., 2018). Most polysaccharide- and protein-based films and coatings are brittle, and to overcome this issue and make them as flexible edible films, plasticisers are incorporated within the film structure (Regubalan et al., 2018). Some of the most commonly used plasticisers include monosaccharides, oligosaccharides, polyols and lipids (Xie, Pollet, et al., 2014). With a proper selection of a plasticiser for a given biopolymer, optimisation of the film mechanical properties with a minimum increase in film permeability could be achieved, as well as enhancement in the film flexibility and resilience is possible (Xie et al., 2014).

Emulsifiers are surface-active compounds with both polar and nonpolar characteristics, capable of modifying interfacial energy at the interface of immiscible systems (water–lipid) (Janjarasskul & Krochta, 2010). In general, these compounds are used for the formation and stabilisation of well-dispersed lipid particles in composite emulsion films or to achieve sufficient surface wettability to ensure proper surface coverage and adhesion to the coated surface (Taarji et al., 2020). Sugar esters and glycerol monooleate, for example, solubilise the essential oil in the aqueous phase resulting in a high antimicrobial activity (Aguirre- Joya et al., 2018). Other potential emulsifiers include acetylated monoglyceride, lecithin, glycerol monopalmitate, glycerol monostearate, polysorbates, sodium lauryl sulfate, sodium stearoyl lactylate, and sorbitan monooleate and sorbitan monostearate (Mendes et al., 2020). In addition, calcium salts could be used as texture enhancers as these salts interact with carboxylated polymers and form a cross-linked network that increases the firmness of the product. Anti-browning agents are also widely used in edible coatings for packaging fruits and vegetables and their products (Vasile, 2018).

Flavour and aroma components of foods may be altered or escape during the processing or storage time due to their volatile nature. Flavouring substances can be extracted via physical, enzymatic, or microbiological methods from animal, marine and plant sources. Some examples of commonly used plants for the development of flavour or aroma include oregano, cinnamon, curcumin, clove, rosemary, in addition to synthetic flavours. Natural aromatic substances are becoming more attractive in the food industry due to increased consumer awareness as being perceived as natural and healthy foods. Interestingly, some flavours are synthesised by living organisms as a defence mechanism or as secondary metabolites, such as flowers (jasmine), herbs (rosemary), buds (clove), leaves (eucalyptus), fruits (citrus), barks (cinnamon), seeds (cardamom), or roots (ginger) (Arnon- Rips & Poverenov, 2016).

## 6. Applications of edible packaging

Edible packaging could be a potential packaging solution for many types of food. To date, there are data indicating that edible packaging has been successfully applied on meat, grains, nuts, cheese, bakery, confectioneries, fruits and vegetables (intact or fresh-cut) and will be briefly described below. The selection of edible packaging mainly is determined by the type of food that is packed as well as by storage time and conditions (Sharma et al., 2020).

### 6.1. Fruits and vegetables

The most-wide application of edible coatings exists in the food group of fruits and vegetables in fresh or preserved forms. Most of the losses in quality of fresh fruit and vegetables occur during storage and transportation. Usually, it includes moisture loss, shrinkage, weight loss, microbial and biochemical change, mechanical damages, and sensory changes that are of common interest to be minimised or prevented. Therefore, taking into consideration that the respiratory processes of these food classes continue long after their harvest, the application of an edible packaging on fresh fruit or vegetables, will affect the gas permeability, in particular, the oxygen diffusion, and thus, inhibit the ripening processes. The products will remain fresh and attractive for an extended period, where the edible packaging acts as a barrier to free gas exchange and prevents the absorption of undesirable odours. The protection of gas exchange through edible coating can also cause modification of atmosphere around the fresh fruits/vegetable and development of anaerobic conditions that lead to alcoholic fermentation and change the sensory characteristics of packed food. Therefore, it is important to make a proper selection of edible materials for fruit and vegetable packaging to achieve an optimal balance of permeability properties. Additionally, this will result in the product keeping the moisture, appropriate adhesion to the product due to its hydrophilic nature, protecting off-flavour development, homogeneous and an attractive (i.e. glossy) appearance, keeping the fruit firm, reducing weight loss, and minimising solute leakage. In addition, these edible packaging can also encapsulate aromatic compounds, antioxidants, pigments, ions that stop browning reactions and nutritional substances (Fritz et al., 2019). Moreover, some examples for edible coatings applied on different fruits and vegetables include broccoli (Alvarez et al., 2013), okra (Gundewadi, et al., 2018), carrots (Villafa˜ne, 2017), tomatoes (Athmaselvi, Sumitha, & Revathy, 2013), cucumber (Raghav & Saini, 2018), papaya (Yousuf & Srivastava, 2015), apricot (Ghasemnezhad, et al., 2010), kiwifruit slices (Allegra et al., 2017), fresh-cut cantaloupe (Marti˜non et al., 2014), apples (Gardesh et al., 2016), strawberry (Tomadoni et al., 2018), cherry tomatoes (Robledo et al., 2018), green beans (Donsì et al., 2015), raspberry (Falc´o et al., 2019), grape (Kim et al., 2014), lime fruit (Maftoonazad & Ramaswamy, 2019), banana (Thakur et al., 2019) and others.

### 6.2. Meat, poultry, fish

Meat, poultry and fish can benefit considerably from edible packaging in terms of product quality and safety, and extending their shelf life (Dong et al., 2020). This packaging type reduces moisture loss, inhibits texture degradation, prevents unattractive dripping of product juices and consequently reduces food loss, spoilage, and waste. Furthermore, edible packaging reduces biochemical product degradation, protects lipids and proteins from oxidation, delays rancidity, and prevents undesired colour changes. Active (antimicrobial) edible materials also contribute to products' microbial safety and decrease the spoilage. Fresh meat cuts and products can be included in this category (Bhagath & Manjula, 2019), as well as pork (Xiong et al., 2020), lamb (Pabast et al., 2018), turkey (Guo et al., 2014).

**6.3. Dairy products**

Relatively high rates of foodborne illness related to dairy such as human listeriosis have emphasised the importance of preventing microbial infection in dairy products. Salmonella is another bacteria that has been found in spoiled cheese (Pourmolaie, et al., 2018). In addition, mould contamination of different dairy products such as cheese during ripening and storage is a problem for the dairy industry. Many species of aspergillus and penicillium are common fungal contaminants of the cheese (Cerqueira et al., 2010). The ancient solution for this problem is physically impregnating the product with spices, herbs or their oils with many studies reporting the usefulness of this form of edible packaging concept in the dairy industry, such as the study examines the cheese packaging into a chitosan-coated nisin-silica liposome with anti-listeria effects (Cui, et al., 2016). Probiotic coating of cheeses can be an ideal vehicle for lactic acid bacteria. Namely, the L. acidophilus and L. helveticus inclusion in edible cheese coverings reduced the presence of the total coliform at ten days (Olivo et al., 2020).

**6.4. Grains and nuts**

In general, grains and nuts are products with relatively low moisture content. Edible packaging has been shown to be useful in controlling undesirable mass transfer between the products and environment. This migration from the food to the outer environment or vice-versa can decrease food quality and alter its sensory characteristics such as dehydration or spoilage, loss of aroma and flavour. In addition, edible packaging can prolong grain and nut quality by protecting from mechanical damages during transport, vibrations, and pressure as well reducing the stickiness of the grains to surfaces that they might come into contact. Active edible packaging which contains antioxidant inclusions could potentially protect the grains and nuts from lipid oxidation, for example (Arnon-Rips & Poverenov, 2016).

**6.5. Baked products and candies**

Edible coatings could be applied on a different baked and extruded products, such as crackers, biscuits and cereals. The loss of their crispiness and softening due to hydration during storage can be effectively managed by use of edible packaging (Jim´enez et al., 2018). Edibles produced with plant essential oils (i.e. clove, oregano) displayed antimicrobial activity against the development of fungi in baked products, consequently improving shelf life (Gavahian et al., 2020). Bread, as the most consumable representative of this group, is an attractive case for application of a variety of edible coatings (Chakravartula et al., 2019). Moreover, candies and confectioneries are an interesting and challenging group of food that can be protected from undesired stickiness, agglomeration, moisture absorption and oil migration by edible packaging (Eyiz, Tontul, & Türker, 2020). Table 3 summarizes edible packaging options for dairy, nuts and bakery products.

**7. Conclusion & Future prospective**

There is a tremendous interest in novel packaging solutions for a variety of food products worldwide. The emergence of new packaging technologies have enabled newly developed products to perform better than providing them with containment and physical protection. The future of edible packaging materials is very promising, and increased innovation within the food industry is both imminent and already occurring. Global consumer demands are a driving force for research and development of novel materials in order to find alternatives for fossil-based packaging materials. Their replacement with recyclable, biodegradable or edible materials, prepared from renewable and sustainable sources, are desired by consumers and the food industry alike. In this context, the use of biopolymers as food packaging possess the advantages of biodegradability, process simplicity, and an ability to be combined with other materials has a considerable potential to reduce the food waste and benefit the environment.

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