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Edible and bio-based food packaging: A review

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Abstract

The development of edible/biodegradable films/coatings is a key and unique field of exploration within food packaging which possesses enormous commercial and environmental potential. The potential use of edible packaging has been well recognized by many research groups and the food and pharmaceutical industry as an alternative or synergistic complement to conventional packaging to enhance food protection and/or recyclability of packaging. Various innovative uses of edible films and coatings have been proposed as both new applications and alternatives to existing technologies. The dry thermoplastic process is rapidly developing as a viable commercial process for the production of edible film-forming materials, which can be used in food-grade coatings and soluble packaging to create more effective and convenient packaging solutions, among others, and with environmentally friendly approaches, are a challenge for research and development in the packaging industry.

Keywords: Edible films, edible coatings, starch, chitosan, egg white protein, whey protein essential oils, plant extracts, polyphenols

Introduction

Of the 78 million tonnes of plastic packaging produced worldwide each year, only 14% is recycled. Nine million tonnes of uncollected lightweight floating plastic ends up in our oceans every year. Most of them come from Most of the recycled plastic is shredded, melted and converted into products such as timber, fleece and carpets, but these products still end up in landfills. Manufacturers are making bottles and shrink wrap thinner and thinner, but the facts remain the same. Plastics are made from non-renewable oil or natural gas developing countries that lack the infrastructure to manage them. The problem is expected to worsen as these countries become wealthier and inevitably begin to consume more processed foods. packaging waste. Resources, and in most cases are never recycled. The use of food packaging is a socioeconomic indicator of population purchasing power or Gross domestic product increase and local (rural and urban) food availability. The utilization of edible packaging can reduce the complexity of overall packaging requirements by allowing conversion from multilayer or multilevel packaging to a single-component package, resulting in source reduction and improved recyclability of the simplified packaging system without compromising protective functions (Krochta 2002) [27]. Edible packaging materials can also be used for nonedible packaging as an O2- or grease-barrier layer to improve protective functions and biodegradability of multilayer packaging (Hong & Krochta 2003, 2004; Han & Krochta 2001, Chan & Krochta 2001a, b; Lin & Krochta 2003, Lee *et al*. 2008) [22, 23, 20, 5-6, 31, 30].

History of Food Packaging

Hundreds of years ago, food was mostly grown and produced locally and therefore did not require packaging. Except, of course, for luxuries such as sugar, which were imported in ships' sacks and barrels. However, as time passed, the population increased, industry developed, and food transportation became essential. The Industrial Revolution brought many innovations, such as metal cans and cardboard boxes. Manufacturing processes have improved significantly, and luxury goods suppliers have agreed that the quality of packaging should reflect the quality of the food.

Quality at the time meant toughness and longevity, so the packaging was designed to serve multiple functions. Great progress has been made in the last 30 years. Polyethylene and polyethylene terephthalate were also developed for food pouches and foil covers, revolutionizing the design of aluminum cans with simpler, more cost-effective designs.

Although invented in the 1950s, the first barcode scanners weren't installed in supermarkets until the mid-1970s.

Since then, barcodes have become familiar to many of us. With the invention of the internet and digital technologies expanding greatly, global business became commonplace and no longer restricted to the mega brands. This meant there was more competition and packaging took on a more important role than ever, after all it was this that made your food item stand out amongst the rest on the shelf.

In 2008 labels and packaging began providing shoppers with even more information and resources by placing quick response (QR) codes on products. Easily scanned by a smartphone these direct the customer to an internet page holding anything from further product information, such as ingredients, to a competition run by the brand.

Throughout the early 21st century, many packaging companies and big food producers have grown a conscience and have begun looking for more ecological solutions to their packaging needs. Recyclable cartons and refillable jars have really taken off, and food retailers continue to come up with innovative solutions every day.

Edible packaging

There are also few historical reports on the use of edible materials as food coatings. Edible packaging is a process pioneered by the Sumerians of Mesopotamia around 3000 BC, and has long been used to make sausages that preserve meat by stuffing it into the intestines of animals.

With a quick look at some aspects of our daily life it is possible to identify many different types of plastics surrounding us. In the food industry, this expansion was also noticeable, mainly because the use of these materials has improved food preservation and extended the storage period of a lot of products.

Around 40% of the petrochemical-based plastics are used for packaging purposes and closely to 60% of plastic packaging are used to pack food and beverages (Groh *et al* 2019.) [18]

Innovative packaging designed for food products with different characteristics, such as higher moisture content, high pressure and modified atmosphere, natural and fresh foods, among others, and with environmentally friendly approaches, are a challenge for research and development in the packaging industry. These biological materials should be renewable, recyclable and have low greenhouse gas emissions in ecosystems. Biomass packaging is made from the materials obtained from the biological sources. Materials obtained from, the biological sources like plant, animals, seafoods, agricultural residues etc. are biodegradable and get composted easily as compared to the synthetic sources. These materials gets degraded by the action of live organisms upon disposal and converted to CO_2, CH4, H_2O, inorganic compounds and returns to nature.

The development and characterization of edible films and coatings have increasingly attracted the attention of biochemists, biotechnologists, and physicists, among others, mainly to the large variety of applications served by bio-based polymers.

The rate of biodegradability of biobased material is dependent on their chemical structure.

Advantages of conventional packaging

Switching to edible food packaging has many advantages. First, most consumers are becoming very environmentally conscious. That means they want to know the waste their purchases create. Edible food packaging eliminates typical waste cycles and does not require recycling. Most edible packaging is edible and compostable, so it degrades easily and doesn't fill up landfills and recycling yards.

Secondly, this type of packaging can be used for various purposes such as food packaging and food preservation. Edible packaging is most commonly used for refrigerated and single-use products. This range can be extended to soups and coffee, allowing the package to melt after exposure to heat. Instead of using sugar casings to preserve certain foods such as grains, milk casein can be used to coat the grains to prevent them from spoiling.

The other advantages includes

- Edible packaging minimizes cycles and does not require recycling, making it the best biodegradable packaging material that never ends up in landfills.
- Natural edible packaging can protect food, leave no residue, and make it nutritious and delicious as the filling.
- Reduces waste and the solid disposal problems.
- Enhance organoleptic properties such as color and sweetness

Edible packaging can be used in food-grade coatings and soluble packaging to create more effective and convenient packaging solutions.

Types of edible packaging materials

Depending on the manufacturing process and manufacturing materials such as polysaccharides, proteins and lipids, edible food packaging is divided into, different categories. Edible packaging materials are traditionally made by dissolving edible food materials in water, alcohol, or a mixture of solvents. Plasticizers are often added to mixtures to improve the flexibility and elasticity of the resulting material. Edible films are made in a variety of ways like Continuous film casting, mood casting, drawdown process. The most important film-forming materials are biopolymers such as proteins, polysaccharides, lipids and resins. They Can be used alone or in combination. The physical and chemical properties of biopolymers strongly influence the properties of the resulting films and coatings. Film-forming materials can be hydrophilic or hydrophobic. However, to maintain edibility, the solvents used are limited to water and ethanol.

Protein-based edible packaging

Protein-based edible films are used on a variety of food products to reduce water loss, limit oxygen uptake, reduce lipid migration, improve mechanical handling properties, and provide physical protection, or provide alternatives to synthetic packaging materials. In addition, protein-based edible films act as carriers for antimicrobials and antioxidants. Similar applications can also be used on food surfaces to control the diffusion rate of preservatives from the food surface into the interior. Another possible application of protein-based edible films is their use in multi-layer food packaging materials together with non-edible films. In this case, the protein-based edible film becomes the inner layer in direct contact with the food material. Edible protein-based films with mechanical and barrier properties have the potential to replace synthetic polymer films.

Corn zein contains a group of prolamins (alcohol-soluble proteins). Zein is insoluble in water except at very low or high pH and is insoluble in anhydrous alcohols (Gennadios & Weller 1990) [14]. Zein coating or casting solutions are usually prepared by dissolving zein in warm aqueous ethyl alcohol or isopropanol. Film formation is thought to involve the development of hydrophobic, hydrogen and constrained disulfide bonds between zein chains in the film matrix as the alcohol evaporates from the film surface (Padua & Wang 2002) [41]. Zein is one of the few proteins used as a commercially successful finishing agent that imparts surface gloss and acts as an O2, lipid and/or moisture barrier to nuts, candies, confectionery and other foods (Krochta & De Mulder-Johnston 1997) [28]. Pharmaceutical tablets are coated with zein to achieve a controlled release of active ingredients (Gennadios & Weller 1990) [14] and to mask the taste of orally administered drugs (Meyer & Mazer 1997) [35]. The use of zein-based coatings has been suggested to reduce the oil uptake of fried foods (Mallikarjunan *et al*. 1997) [32]. Moderate gas barrier zein films reduce moisture loss and respiration rate of vegetables (Park *et al*. 1994) [42].

Soy protein isolate (SPI) is most commonly used to prepare film-forming solutions, although 7S and 11S fractions have also been used (Kunte *et al*. 1997) [29]. During thermal denaturation of casting solutions, soy protein films are formed through intermolecular disulfide bonds and hydrophobic interactions. Cysteine residues, present in both 7S and 11S fractions, undergo polymerization via a sulfhydryl-disulfide exchange reaction during heat treatment to form a cohesive continuous covalent film network upon cooling. SPI films can be applied to a precooked meat product to control lipid oxidation and limit surface moisture loss (Wu *et al*. 2000) [56]. These films have good potential to carry flavors (Kunte *et al*. 1997) [29] or antimicrobial and antioxidant compounds (Tables 2 and 3). SPI films may also find applications as microencapsulating agents for flavors and drugs or in fruit, vegetable and cheese coatings (Petersen *et al*. 1999) [45]. SPI protective coatings can also be applied to certain food products, such as meat pies and high moisture pies, which require highly water vapor permeable films (Gennadios *et al*. 1993a) [15].

Collagen is a hydrophilic protein rich in glycine, hydroxyproline and proline, therefore it swells in polar liquids with high solubility parameters.

Collagen sausage casing is one of the most commercially successful edible protein films. Wrapping chilled and thawed beef round steak with a collagen film reduced exudation without significantly affecting color or lipid oxidation (Farouk *et al*. 1990) [13]. The use of collagen-based films has been proposed for processed meats to reduce loss of coagulation, increase juiciness, allow easy mesh removal after cooking or smoking, and to absorb liquid exudates from various cooked meat products.

Gelatin (E441) is obtained by hydrolysis of collagen. Gelatin films can be made by drying a heat-reversible gelatin gel formed by cross-linking between the amino and carboxyl components of the side groups of amino acid residues.

Gelatin coatings can reduce O2, moisture and oil migration or carry bioactive components (Krochta & De Mulder-Johnston 1997) [28]. Gelatin is widely used as an encapsulating agent in hard and soft gel capsules for low-moisture or oil-based food additives, dietary supplements, and pharmaceuticals (Baldwin 2007) [2].

Caseins (are mostly phosphoproteins that form colloidal micelles in milk stabilized by calcium phosphate bridges. Caseins are characterized by a low level of cysteine. Consequently, they cannot form the extensive covalent inter- or intramolecular disulfide bonds that would render water-insoluble films by thermal denaturation (Chen 2002) [7]. Casein molecules have an open, flexible, random conformation that facilitates film formation from aqueous solution due to their ability to form extensive intermolecular hydrogen and electrostatic bonds and hydrophobic interactions (McHugh & Krochta 1994b) [34]. Casein films have been investigated to act as moisture barriers for water-soluble pouches, fresh produce, dried fruit and frozen foods. The excellent O2 barrier of casein-based films at low aw has been shown to slow nut lipid oxidation. In addition, casein films have great potential as carriers of flavor, nutrients or bioactive components (Gennadios *et al*. 1994) [16].

Whey proteins (WPs) remain soluble after the casein is precipitated at pH 4.6 during the cheese making process. WP are commercially available as whey protein concentrates (WPC; 25-80% protein) and whey protein isolates (WPI;> 90% protein). WP are globular and heat labile in nature. β-lactoglobulin, the predominant protein in whey, contains one free thiol group and two disulfide groups per monomer; four hydrophobic groups are located inside the globular structure.

Research on the formation of WP films mainly involved thermally induced molecular thiol-disulfide exchange reactions. Heating modifies the native globular structure into unfolded protein filaments, exposing internal SH and hydrophobic groups that promote intermolecular SS bonding and hydrophobic interactions upon drying to form water-insoluble films (McHugh & Krochta 1994b) [34]. Perez-Gago *et al*. (1999) [43] observed that native WPI has the ability to form a water-soluble edible film without thermal denaturation. The cohesion of native WPI films mainly depends on intermolecular H-bonding formed after coacervation and solvent evaporation between native globular molecules, with most of the hydrophobic and SH groups buried inside the molecule.

Both native and heat-denatured WPI films are transparent, tasteless, and have similar WVP and OP; however, they have different solubility and mechanical properties. The decomposed structure and disulfide bond of the thermally denatured WP film contributes to water insolubility and to stronger, stiffer, stiffer and more extensible films (Perez-Gago & Krochta 2002) [44]. The low-energy bonds and globular structure of native WP films account for complete solubility in water and lower strength, stiffness, and extensibility (Pe´rez-Gago *et al*. 1999) [43]. WP films and coatings have been used as protective barriers to reduce O2 uptake and rancidity in roasted peanuts (Mate´ *et al*. 1996) [33] and frozen king salmon (Stuchell & Krochta 1995) [52] and to reduce the decay of brittle freeze-dried foods. WPI films with O2 scavenging functionality have been developed by incorporating ascorbic acid (Janjarasskul & Krochta 2006) [24]. WPI coatings containing ascorbic acid reduced OP (Janjarasskul & Krochta 2006, Min & Krochta 2007) [24, 38] and were shown to significantly slow lipid oxidation in coated peanuts (Min & Krochta 2007) [38], infant formula, peanut butter and mayonnaise (Janjarasskul & Krochta). The ability to carry and control the release of antimicrobials has been investigated (Min *et al*. 2005a, b) [36-37].

Polysaccharides based edible packaging

Polysaccharides are long-chain polymers formed from mono- or disaccharide repeating units linked together by glycosidic bonds. Due to the large number of hydroxyl groups and other hydrophilic groups present in their structure, H-bonds play a significant role in the formation and characteristics of the film. In general, polysaccharide films are formed by the disruption of interactions between long-chain polymer segments during the coacervation process and the formation of new intermolecular hydrophilic and H-bonds upon evaporation of the solvent to form the film matrix.

Polysaccharides include starches, non-starch carbohydrates, gums, and fibers. Polysaccharide sequences are simple compared to proteins. However, the conformation of polysaccharide structures is more complex and unpredictable, resulting in much higher molecular weights than proteins. Most carbohydrates are neutral, but some gums are mostly negatively charged. Some negatively charged gums such as alginate, pectin and carboxymethyl cellulose exhibit markedly different rheological properties under acidic than under neutral or alkaline conditions.

Various polysaccharides and their derivatives have been tested for potential use as edible coatings because they are abundant, low in cost, and easy to handle. Polysaccharides have good film-forming properties with a wide range of coating solution viscosities. Polysaccharide films exhibit good mechanical and gas barrier properties (Baldwin *et al*. 1995) [3] and are effective barriers against oil and lipids, but offer little resistance to water migration. Similar to other hydrophilic films, humidity significantly affects their functional properties.

Polysaccharides can be easily modified to improve their physicochemical properties by salt addition, solvent change, thermal gelatinization, pH change, chemical modification of hydroxyl groups, polysaccharide cross-linking, polysaccharide hydrolysis, and the use of nanotechnology (De Moura *et al*. 2009) [11].

Cellulose consists of linear chains of (1→4)-β-D-glucopyranosyl units. Cellulose is insoluble in aqueous solution due to its tightly packed polymer chains and highly crystalline structure due to its regular structure and number of hydroxyl groups. Water solubility can be increased by esterification to form cellulose derivatives. Substitution of hydroxyl groups on glucose units with bulkier groups helps to separate polymer chains in the crystal structure by disrupting intramolecular H-bonds. Common commercial water-soluble cellulose ethers, including methylcellulose, hydroxypropyl cellulose (HPC), hydroxypropyl methylcellulose (HPMC) and carboxymethylcellulose (CMC) all have good film-forming properties. The degree of substitution, types of functional group substitution, and polymer chain length affect permeability, mechanical properties, and solubility (Sanderson 1981) [49].

Edible coatings of these cellulose ethers have been applied to various foods to form barriers to moisture, O2, or oil. Because of their ability to form heat-induced gelatinous coatings, MC and HPMC have been used as batter additives to reduce oil uptake and moisture loss during deep-fat frying (Sanderson 1981, Balasubramaniam *et al*. 1997) [49, 1]. MC and HPMC solutions are widely used in the pharmaceutical industry for tablet coating. Water-soluble edible pouches from MC and HPMC are used commercially to deliver pre-weighed dry food ingredients.

Starch: Amylose is an interlayer polymer composed of (1→4)-α-D-glucopyranosyl monomers. Amylopectin is a highly branched molecule that contains an amylose backbone with D-glucopyranosyl side units linked by α-1,6-glycosidic linkages. The native starch molecules arrange themselves in the form of starch granules in which amylose and amylopectin are H-bonded in an ordered manner of semicrystalline domains alternating with amorphous rings. To increase water solubility, starch with a high amylose content can be partially etherified with propylene oxide to obtain hydroxypropyl derivatives. Amylose, high-amylose starch, and high-amylose hydroxypropyl starch were used to form self-supporting films by casting from aqueous solutions of gelatinized starch.

Amylose and hydroxypropyl amylose films have been developed as protective edible coatings on foods and encapsulating agents to provide an O2 or lipid barrier and improve appearance, texture and handling. Edible starch films and coatings are commonly used in bakery, confectionery, dough and meat products. Chitosan. Chitin is a β-1,4-linked linear polymer of 2-acetamido-2-deoxy-D-glucopyranosyl residues. Chitosan is produced by fusing chitin with alkali. It is not currently approved for use in the United States as a food additive. Chitosan films can be formed by casting acidic aqueous solutions. The viscosity of chitosan solutions can vary depending on the type of organic acid solvent used, which affects the properties of the film (Rhim *et al*. 1998) [47]. Chitosan coatings semi-permeability can be used to increase the post-harvest shelf life of fresh fruit (Wang *et al*. 2007) [55]. The amino groups of chitosan provide opportunities for chemical modification as the cationic groups can react with any negatively charged substances, e.g. fats, cholesterol, basic ions and proteins. The cationic property of chitosan offers antimicrobial and antioxidant activities, as well as the ability to carry and slowly release functional ingredients (Coma *et al*. 2002) [8]. The use of chitosan coatings to delay enzymatic browning in fresh produce has been reported (Zhang & Quantick 1997) [57]. Pectins (E440) are water-soluble anionic polymers composed mainly of (1→4)-α-D-glucopyranosyl uronic acid units. Pectins with a degree of esterification (DE) above 50% are referred to as high methoxylated pectin (HMP) and below 50% are referred to as low methoxylated pectin (LMP). Differences in methyl ester and DE content affect the solubility and gelation properties of pectin (Baldwin *et al*. 1995) [3]. HMP forms gels with sugar and acid, especially in jams and jellies. LMP, produced by chemical desertification, forms gels in the presence of divalent cations. Calcium cations bridge adjacent LMP chains through ionic interactions and with interchain H-bonding provide a 3D gel network.

An edible pectin film can be made by evaporating the water from the pectin gel. Although pectinate coatings are not adequate moisture barriers, they can slow water loss from coated foods by acting as a sacrificial agent when moisture evaporates from their gel matrix, rather than dehydrating the food significantly. Pectin coatings have been investigated for their ability to slow moisture loss and lipid migration and improve food handling and appearance (Kester & Fennema 1986) [26]. Alginates (E405) are salts of alginic acid, which is a linear (1→4) linked polyuronic acid containing three types of block structures: poly-β-D-mannopyranosyl uronic acid (M) block, poly-α-L- gulopyranosyl uronic acid (G) blocks. and MG blocks containing both polyuronic acids. These highly anionic polymers have the ability to form instant gel structures by reacting with divalent or trivalent cations, without heating or cooling, similar to LMP.

Alginate films can be formed by evaporation of the solvent from the alginate gel or by a two-step process that involves drying the alginate solution followed by treatment with a calcium salt solution to induce immediate cross-linking at the interface.

Carrageenan (E407) is a complex mixture of several polysaccharides. The three major carrageenan fractions, kappa (κ), iota (ι) and lambda (λ), differ in sulfate ester and 3,6-anhydro-α-D-galactopyranosyl content, resulting in varying degrees of negative charge and water solubility. Thermoreversible carrageenan gels can be used as food wrappers to slow moisture loss from coated foods by acting as a sacrificial agent (Kester & Fennema 1986) [26]. Carrageenan has been applied to various foods to carry antimicrobial agents and reduce moisture loss, oxidation or decay (Nieto 2009) [39] and has been studied for flavor encapsulation (Fabra *et al*. 2009) [12]. Gum arabic (E414), gum ghatti, gum karaya, and gum tragacanth are structurally complex heteropolysaccharides and materials commonly used as packaging coatings.

Guar gum (E412) is a straight-chain β-D-mannopyranosyl polysaccharide with single α-D-galactopyranosyl units attached as side chains in a 1:2 ratio. Guar gum is soluble in both cold and hot water and provides high-viscosity solutions. Calcium can cross-link guar gum and cause it to gel.

Gellan gum (E418) is a water-soluble polysaccharide consisting essentially of the repeating tetrasaccharide unit (1→3)-β-D-glucopyranosyl, (1→4)-β-D-glucopyranosyl uronic acid, (1→4)-β-D-glucopyranosyl and (1->4)-α-L-rhamnopyranosyl units. Gel of gellan gum can be made by heating a solution in the presence of cations. Upon cooling, the polymer chains can take up double helices that aggregate into a weak gel structure supported by van der Waals attractions. In the presence of cations, double helices form cation-mediated aggregates leading to the formation of strong gel associations. Gel properties are strongly influenced by cation type, ionic strength and gum concentration. Xanthan gum (E415) are also extracellular microbial polysaccharides showing good film-forming ability (Nieto 2009) [39].

Lipids based edible films

Many edible lipid materials have been used as protective coatings against moisture transfer and to add gloss. Unlike other macromolecules, lipid and resin compounds are not biopolymers. They do not have a large number of repeating units linked by covalent bonds to form a large molecular structure. They are thus fragile and generally do not form cohesive, self-supporting film structures. Because of their relatively low polarity, lipids and resins have been incorporated into edible film-forming materials to provide a moisture barrier in composite films (Greener & Fennema 1989) [17]. However, the use of lipids in edible packaging materials has disadvantages such as their waxy taste and texture, greasy surface, and potential rancidity.

Neutral esters of glycerol and fatty acids, including mono-, di, and triacylglycerides, have been used alone or in combination with other edible ingredients to coat food products. Properties, such as solubility and resistance to water vapor, of fatty acids and lipids derived from them are significantly dependent on their physical state, chain length and degree of saturation. In general, an increased degree of acyl chain unsaturation or branching and/or a decrease in carbon chain length leads to an increase in WVP (Kamper & Fennema 1984) [25]. This is a consequence of the increased mobility of the hydrocarbon chains and the less efficient lateral packing of the acyl chains caused by the interchain reduction of van der Walls attraction.

Acetylated monoglycerides (E471) are modified fats in which one fatty acid attached to a glycerol molecule is replaced with acetic acid. The degree of acetylation and the type of monoglyceride give acetic acid esters with different properties. The WVP of acetic acylglycerol improved with increasing degree of acetylation, which was hypothesized to result from differences in crystal packing or removal of free hydroxyl groups that would otherwise interact with migrating water. Some associated problems include a sour, bitter taste and the tendency of highly saturated acetylated glycerides to crack and peel during storage (Bourlieu *et al*. 2008) [4]. Fatty acids, and sucrose esters of fatty acids may also be used as lipid coatings.

Waxes: Waxes are esters of a long-chain fatty acid with a long-chain alcohol. Due to the very low content of polar groups, they are significantly more resistant to water diffusion than most lipid or non-lipid edible films. (Kester & Fennema 1986) [26].

Both natural waxes, e.g., carnauba wax (E903) candelilla wax (E902), rice bran wax (E908), beeswax (E901), and synthetic waxes and petroleum wax (E905c), have been used as protective coatings, alone or in combination with other ingredients (Baldwin 2007) [2].

Resin: Edible resins such as shellac (E904), terpene resin, and wood rosin (E445) are used to add gloss to food commodities (Baldwin 2007) [2]. Shellac consists of a complex mixture of aliphatic and alicyclic polymers of hydroxyl acids such as aleuritic and shellolic acids. It is soluble in organic solvents and in alkaline solutions. Shellac is widely used as an edible coating for confectionery and fresh produce and as an enteric coating for pharmaceuticals (Rhim & Shellhammer 2005, Baldwin 2007) [48, 2].

Film Additives: Film additives are materials other than film-forming substances incorporated to improve structural, mechanical and handling properties or to provide active functions of films.

Plasticizers: Plasticizers are typically low molecular weight hydrophilic agents that are added to film-forming formulations to improve the mechanical properties of the film by intercalating into their polymer network and competing for H-bonding along the polymer chains. Commonly used plasticizers in edible packaging are mono-, di-, or oligosaccharides (e.g., glucose, fructose-glucose syrups, and sucrose), polyols (e.g., glycerol, sorbitol, glycerol derivatives, and polyethylene glycols), and lipids and derivatives (e.g., phospholipids, fatty acids and surfactants). In general, the selection of plasticizers requires consideration of plasticizer compatibility, efficacy, stability, and cost effectiveness (Sothornvit & Krochta 2005) [51].

Emulsifiers: Emulsifiers are surface-active compounds of both polar and nonpolar character, capable of modifying the interfacial energy at the interface of immiscible systems, such as the water-lipid interface or the water-air surface.

Emulsifiers are necessary to form and stabilize 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 (Krochta 2002) [27]. Some common emulsifiers are acetylated monoglyceride, lecithin, glycerol monopalmitate, glycerol monostearate, polysorbate 60, polysorbate 65, polysorbate 80, sodium lauryl sulfate, sodium stearoyl lactylate, sorbitan monooleate, and sorbitan monostearate. Many proteins have emulsifying properties due to their amphiphilic nature.

Antimicrobial agents. Incorporation of both natural and synthetic antimicrobials into various edible packaging has been developed as an effective alternative to control the growth of microorganisms.

Organic acids and their salts: Benzoic acid (E210) and its salts are most effective in the undissociated form at pH 2.5-4.0. This preservative is more effective against yeasts and molds than bacteria. Sorbic acid (E200) and its salts are effective in the pH range of 3.0-6.5 against a wide range of yeasts and molds and lactic acid bacteria. Acetic (E260), lactic (E270), propionic (E280), and fumaric (E297) acids may also be used in coatings and contribute to antimicrobial activity.

Chitosan: The antimicrobial activity of chitosan is most effective against yeasts and fungi, followed by gram-positive bacteria and gram-negative bacteria. Its mechanism of antimicrobial action was proposed to be the harmful leakage of microbial protein and intercellular components as a result of the interaction between the positively charged chitosan and the negatively charged microbial cell membrane. Chitosan also chelates trace metals, preventing microbial growth and toxin production (Cuero *et al*. 1991) [9].

Plant extracts. Extracts of essential oils from plants such as grapefruit seed, cinnamon, allspice, clove, thyme, rosemary, onion, garlic, radish, mustard, horseradish and oregano are rich in phenolic compounds such as flavonoids and phenolic acids, which show a wide range of biological effects, including antioxidant and antimicrobial activity (Oussalah *et al*. 2004) [40]. These naturally occurring antimicrobial agents can be added to foods without being labeled as antimicrobial agents or preservatives (Suppakul *et al*. 2003) [53].

Bacteriocins: Bacteriocins are protein-containing macromolecules produced by various bacteria that have different antibacterial spectra, modes of action, and chemical properties. In general, they are heat stable, hypoallergenic and easily broken down by proteolytic enzymes in the human intestinal tract. Numerous bacteriocins have been characterized, such as colicins (Escherichia coli), lacticin (*Lactococcus lactis*), pediocins (*Pediococcus acidilactici*) and nisin (*Lactococcus lactis*). Nisin (E234) remains the most commercially important bacteriocin because of its history of safe use and demonstrated efficacy against Gram-positive pathogenic and spoilage bacteria. Nisin interacts with sulfur-containing compounds in bacterial membranes, disrupting their semipermeable function and causing cell lysis (Thomas *et al*. 2000) [54].

Enzymes: Lysozyme and lactoperoxidase are widely studied antimicrobial enzymes isolated from various natural sources, e.g. milk. Lysozyme is a single-chain protein that has the ability to hydrolyze the β (1→4) glycosidic bonds between N-acetylmuramic acid and N-acetylglucosamine found in the peptidoglycan cell walls of both Gram-positive and Gram-negative bacteria. Loss of structural integrity of cell walls causes bacterial cell lysis (Shah 2000) [50]. Lysozyme is less effective against Gram-negative bacteria because of the lipid-based outer membrane over their cell walls. Lactoperoxidase catalyzes the oxidation of the thiocyanate ion, forming oxidation products such as hypothiocyanite and hypo thiocyanic acid. These inhibit microorganisms by oxidizing the sulfhydryl groups of microbial enzymes and other proteins, which results in structural damage to cytoplasmic membranes that causes the harmful leakage of potassium ions, amino acids, and peptides from microbial cells (Kussendrager & van Hooijdonk 2000) [58].

Antioxidants: Antioxidants are chemical compounds that delay the onset or slow the rate of oxidation reactions. Antioxidants are broadly classified according to their mechanism of action as primary and secondary antioxidants. Primary antioxidants or chain-breaking antioxidants are free radical acceptors that slow down the initiation or propagation step of autoxidation. Examples are phenolic antioxidants, including butylated hydroxyanisole (E320), butylated hydroxytoluene (E321), propyl gallate (E310), and tert. Tocopherols are the most commonly used natural primary antioxidants. Secondary or preventive antioxidants slow down oxidation by several different effects,

by chelating pro-oxidizing metals, adding hydrogen to primary antioxidants, breaking down hydroperoxides into non-radical species, deactivating singlet O2, absorbing UV radiation, capturing O2, or supporting the antioxidant activity of primary antioxidants. Citric acid (E330), ascorbic acid (E300), ascorbyl palmitate (E304) and acetic acid (E260) are synergists.

Metal sequestrants such as ascorbic acid, citric acid, phosphoric acid (E338), and erythorbic acid (E315) inhibit polyphenol oxidase activity that causes browning in fresh-cut produce. Numerous plants have been identified as sources of natural phenolic compounds with antioxidant activity, such as herbal extracts (eg, rosemary, sage, thyme), sesamol (sesame seed), tea catechins, and gossypol (cotton).

Challenges and opportunities

The potential of edible packaging has been well recognized by many research groups and the food and pharmaceutical industry as an alternative or synergistic complement to conventional packaging to enhance food protection and/or recyclability of packaging. Various innovative uses of edible films and coatings have been proposed as both new applications and alternatives to existing technologies. The dry thermoplastic process is rapidly developing as a viable commercial process for the production of edible packaging, as a number of edible packaging materials derived from by-products or waste from the food industry are being researched and developed. Nanocomposites are also at the forefront of edible packaging research and development.

Nanotechnology allows scientists to engineer the nanostructure of packaging materials to achieve desired barriers and mechanical properties, carry bioactive ingredients, and better perform their designed functions. However, edible packaging still needs to overcome several challenges to achieve significant commercial use.

Challenges

Edible packaging is not as new as some might think, and research has been going on for decades. Some people think it's normal to throw away the package somewhere as it will disappear on its own. The United Nations said in its report: “Labeling a product as biodegradable can be seen as a technical solution that absolves individuals of liability, and can be reluctant to act.

Reluctance of consumers to eat cutlery and food packaging. Additionally, they may be skeptical about the sanitary aspects of edible packaging, whether it protects food from contamination like regular packaging.

Another disadvantage is that the use of edible foils or coatings (for hygiene reasons) usually requires non-edible packaging. In addition, edible packaging is sensitive to various environments and requires careful handling during storage and transportation.

In general, a lack of knowledge and data hinders the design of edible films for the required specifications. Since edible packaging serves both as packaging and as part of food, it must meet strict requirements and challenges.

Edible packaging components must me*et al*l required food product regulations (Guilbert & Gontard 1995) [19]. Depending on their application, edible films and coatings can be classified as food products, food additives, food additives, food contact substances or food packaging materials (Debeaufort *et al*. 1998) [10]. In the case of pharmaceutical and nutraceutical applications, there may be other regulations.

Materials used in the creation of edible packaging must be generally recognized as safe (GRAS) for the intended use or approved by the United States Food and Drug Administration (FDA) Code of Federal Regulations or the US Pharmacopoeia/National Regulations. Edible packaging materials and additives must be used in accordance with good manufacturing practice (GMP) (ie, food grade, prepared and handled as a food additive) and within any FDA restrictions (Krochta & De Mulder-Johnston 1997) [28]. Current classification and regulations of food ingredients can be found in the FDA's Everything added to Food in the United States (EAFUS) database. Edible packaging ingredients must be declared on the label under the Federal Food, Drug and Cosmetic Act (21 USC 343). Edible packaging made from common allergens (ie milk, eggs, peanuts, tree nuts, fish, shellfish, soy, wheat) must be clearly labeled to provide information to consumers with allergies or intolerances to certain food ingredients in accordance with food allergen labeling and Consumer Protection Act 2004.

The potential use of edible materials is significantly influenced by consumer acceptance issues, including sensory properties, safety, marketing, and cultural and religious restrictions on the use of new materials and applications. As food ingredients, edible packaging materials must have neutral sensory properties or be compatible with edible packaged foods to avoid detection during consumption.

Consumers are increasingly aware of the labels on what they eat. Although the FDA requires food manufacturers to list ingredients and allergens on labels, new edible film-forming materials or applications may pose problems for sensitive consumer groups with allergies or cultural/religious restrictions. Such labeling regulation is limited to only eight major allergens and is poorly enforced in fresh produce, bulk, institutional or food applications. Additional safety issues related to potential changes in the microflora of packaged/coated food products with the new application of edible packaging also need to be addressed.

Commercialization of edible packaging also depends on marketing factors including price, consumer reluctance to use new materials, and special attention paid to any special instructions required for opening, cooking, consuming packaged/coated foods, or disposing of packaging.

Currently, the production of edible films is mostly on a laboratory scale and is considered expensive compared to synthetic plastic films. Research into cost reduction and larger scale production is essential to support the feasibility of commercialized edible packaging. The feasibility of commercialized systems depends on the complexity of the production process, the size of the investment for film or coating equipment, potential conflicts with conventional food packaging systems and manufacturers' resistance to using new materials (Han & Gennadios 2005) [21].

In addition, food manufacturers require a long shelf life of products in interstate or international trade. Edible packaging materials are themselves prone to biodegradation, and therefore their protective functions are stable for a shorter period of time than conventional packaging. Therefore, the stability and safety of edible packaging under intended storage/use conditions requires investigation.

Opportunities

In recent years due to their potential to reduce and/or replace conventional, non-biodegradable plastics development of edible/biodegradable films/coatings for effective food packaging has generated considerable interest among the peoples. As food manufacturers require packaging materials to be food grade, maintain/enhance product shelf-life stability and safety and utilize nominal values of packaging, the reduction or replacement with alternative biodegradable forms would clearly allow improvement in overall operating costs while reducing waste streams. EU regulatory pressures, coupled with indirect demands via consumer groups on EU food processors and packaging manufacturers, to develop/utilize ‘environmentally friendly’ packaging systems are increasing. Research development in the area of edible/biodegradable films/coatings is a key and unique field of exploration within food packaging which possesses enormous commercial and environmental potential.

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