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EDIBLE COATINGS – FORMATION, CHARACTERISTICS AND USE – A REVIEW

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The increased consumer demand for food products characterised by high quality and a long shelf-life has initiated the development of mildly preserved products that keep their natural and fresh appearance for the longest possible time. Edible coatings have been long used empirically for food protection and shelf-life prolongation. A growing interest in edible coatings has been observed in the past few years. This paper characterises edible coatings, natural materials/biopolymers used in the production of edible coatings and their application in the food industry.

INTRODUCTION

The growing demand for high quality, ready-to-eat food products with a long shelf-life contributes to the development of new processing technologies which ensure that the product's natural properties and appearance are not significantly altered [Guilbert *et al*., 1996].

In general, edible coatings consist of a thin layer of material which is formed around the food product as film or which is formed outside of the product and placed on or between its components [Krochta & de Mulder-Johnston, 1997]. Edible coatings may be applied directly on the surface as additional protection to preserve product quality and stability. The requirements imposed on edible coatings are determined by the specific properties of the product (such as water content) and changes in those properties during production and storage [Guilbert *et al*., 1996].

There are several reasons for investigating edible coatings. One of the them is the introduction of new food product categories, such as safe, convenience and high quality products. Yet the main reason is the need to reduce the volume of waste through the use of packaging made of naturally occurring polymers which replace synthetic materials. Edible coatings offer such a solution. They protect food against the loss of nutrients (*i.e.* permit water vapor, oxygen and carbon dioxide permeation). In practice, coatings which control the rate of transport of the product's molecular components from the inside to the outside of the packaging may slow down adverse reactions which are responsible for undesirable changes in food products. The effectiveness of edible coatings is determined by their mass transport properties [Buonocore *et al*., 2003].

Food coating attracted widespread interest in the past decades. A wide range of scientific publications were devoted to the analysis of suitable coating materials and the relevant production methodology. Contemporary coatings not only reduce the migration of water vapor, oxygen, carbon dioxide, aromatic compounds and lipids, but they may also play the role of a carrier of substances such as antioxidants, preservatives, aromatic substances, colorants, *etc*. Some coatings enhance the mechanical properties of the products they cover [Krochta & de Mulder-Johnston, 1997; Pranoto *et al*., 2005].

The main role of edible coatings is to preserve the high quality of a food product [Longares *et al*., 2004; Wan *et al*., 2005]. Since coatings are consumed together with the product, their properties and composition have to comply with the requirements imposed on food products, which necessitates the introduction of new rules to regulate their safety and environmental impact.

In the processing industry, food is coated with artificial and natural substances. The latter may be consumed with the food product. They allow for the selective transport of gas, water vapor and electrolytes to the environment and the product, while protecting the product from harmful microorganisms. Polymers produced by living organisms – proteins, carbohydrates and fats – can be used as raw materials in the production of protective coating which prolongs the shelf-life of many food products [Kowalska & Lenart, 1999]. The main components of edible coatings are proteins, fats and polysaccharides [Cuq *et al*., 1994; Koelsch, 1994].

In complex food products, the potential use of edible coatings as a barrier separating various components may be limited due to their effect on the embedded nutrients [Longares *et al*., 2004].

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Polymer-based edible coatings attract significant interest due to their environmentally-safe properties and the possibility of application in the food packaging industry [Debeaufort *et al*., 1998; Peterson *et al*., 1999; Weber *et al*., 2002; Rhim *et al*., 2007].

During storage and distribution, food products are subjected to constant biological, chemical and physical change [Hong & Krochta, 2006]. Some changes are desirable, such as the ripening of fruit and cheese, while others, such as the loss or absorption of moisture, lead to product quality deterioration. To guarantee adequate product quality, attempts are made to improve the mechanical resistance of the product's surface to damage during transport, distribution and sale and to preserve the product's characteristic features for as long as possible. Edible coatings preserve the product's natural physical properties, improve its structural properties, texture and strength.

Edible coatings were first used in the 12th century when wax was applied to reduce moisture loss in oranges and lemons in China. In the 16th century, food products were coated in fat to control moisture loss. In 1930, paraffin was first used for citrus fruit protection in the USA, and in 1950, the list of coatings was expanded to include carnauba wax and oil-in--water emulsion to protect fresh fruit and vegetables. Contemporary edible coatings have various applications, including meat product coatings and chocolate coatings for nuts and confectionery products [Cagri *et al*., 2004].

The concept of applying edible coatings to protect food is not a new invention and its first documented use dates back to 1800 [Allen *et al*., 1963]. Nevertheless, edible coatings are still not widely used in the food processing industry. Scientific research contributes to the development of coating technology and an increased interest in coated food products [Li *et al*., 2006].

BIODEGRADABLE POLYMERS

Natural polymers are much more suitable components for the production of food packaging than synthetic polymers. Above all, natural polymers are biodegradable. Biopolymers may be applied in the production of food coatings and packaging to replace undurable plastic packaging [Hong & Krochta, 2003; Cho *et al*., 2007].

Polymers from renewable sources (biopolymers) can be generally classified into three categories according to the applied production method [Peterson *et al*., 1999].

1. Polymers obtained directly from natural materials (mainly plants). Examples include polysaccharides, such as starch and cellulose, and proteins such as casein and wheat gluten.

2. Polymers produced in the process of classical chemical synthesis from monomers of biological materials. Examples include polyactide, biopolyester from lactic acid monomers. These monomers are obtained in the process of fermentation of hydrocarbon chemical components.

3. Polymers produced by microorganisms or genetically modified bacteria. The best-known example of this polymer is polyhydroxyisobutyrate, hydroxyisobutyrate (HB) and hydroxyvalerate (HV) copolymers.

The practical applications of biopolymers are limited by their production technology as well as high production costs.

As renewable materials, proteins are traditionally used as binding agents (binders) and are also applied in the production of edible films and coatings. They also play a minor role in the production of biodegradable edible films. Proteins are attractive polymers for the pharmaceutical industry due their vast functionality and the high availability of diverse molecules. Even though they are not completely hydrophobic, protein coatings may constitute an effective barrier for gas and water [Miller & Krochta, 1997].

COATING PRODUCTION

Various methods of producing edible coatings are described by scientific literature. Differences in methodology result from the type, form and quantity of material, the applied additives, drying conditions and the material onto which the coating solution is poured for drying.

There are various techniques of producing edible coatings. The most popular method involves the removal of solvent which was used to make the coating solution. This process relies on physical and chemical intermolecular interactions to create and stabilize a continuous structure. Macromolecules in the coating solution are diluted in solvent such as water, ethanol or acetic acid, and are combined with additives. In this case, the solvent solution is poured out to form a thin layer, it is dried and removed from the surface [Cagri *et al*., 2004].

Edible coatings may be produced with the use of various components and techniques. The raw materials which are most frequently applied in the production of edible coatings are natural polymers, such as proteins, carbohydrates, fats, wax and resin. In the carbohydrate group, various forms of cellulose are used, including methyl cellulose, carboxymethyl cellulose, hydroxypropylcellulose, as well as starch and the products of starch hydrolysis (dextrins), pectins, alginate and plant resins. The most commonly used proteins are: albumin, zein, soy protein, milk protein and collagen. Lipid components of edible coatings may include fatty acids and their esters, mono-, di- and triglycerides, bee wax, carnauba wax and shellac, an edible resin [Kester & Fennema, 1986; Krochta & de Mulder-Johnston, 1997; Ogonek & Lenart, 2002].

Coatings comprising a single polymer component are often fragile and brittle. To remedy that problem, plasticizers are added to the coating solution [Cho & Rhee, 2002]. The most effective plasticizers are those whose structure is similar to the polymers which make up the coating [Banker, 1966]. Plasticizers are added to the coating solution to give it an elastic structure. If a high number of plasticizers are used, the moisture barrier and the mechanical properties of coatings deteriorate. Additives may also have a distinctive aftertaste and a high price, therefore the plasticizer to polymer ratio is the key parameter in determining the functional properties of coatings [Coupland *et al*., 2000]. The plasticizer is inserted between the molecular chains of polymers and their physical and chemical bonds increase the cohesiveness of the coating net, and they effectively soften and stretch the structure. The most commonly applied plasticizers are polyols (glycerol, sorbitol, glycol polyethylene), sugars (glucose, honey) and lipids (monoglycerides, phospholipids) [Park *et al*., 2000]. It is very important that the right plasticizer is selected for polymer coatings since its strong effect could significantly modify the physical and chemical properties of polymers. Plasticizers are added mainly for the purpose of increasing the film's elasticity and to make it less brittle [Yang & Paulson, 2000].

The wide variety of techniques and methods involved in the production of edible coatings indicates that there are many options of applying natural polymers in the production process, subject to their function and purpose. The available food additives modify the coating structure and can be applied to obtain the desired coating properties, depending on the raw materials and products used. Edible coatings offer a promising solution to the problem of prolonging the shelf-life of a product and modifying its structural and sensory properties.

CHARACTERISTICS OF EDIBLE COATINGS

Edible coatings comprising polysaccharides (cellulose and its derivatives, starch and its derivatives, resins) or proteins (gelatin, zein, milk proteins, gluten) have the required mechanical and optical properties (which fluctuate at high humidity levels), and are marked by low water vapor barrier properties. On the other hand, coatings that consist of lipids (wax, oil and derivatives) or polyesters (polyactide, poly-β-hydroisobutyrate) are characterised by highly satisfactory barrier properties, but usually form matte surfaces of relatively low elasticity. Starch is the most commonly used polymer in coating production, mainly due to low cost, high availability and the relative ease of use [Guilbert *et al*., 1996]. Protein coatings are hydrophilic and their barrier properties are determined by the quantity of plasticizer and moisture content [Fang *et al*., 2002].

Edible coatings may comprise one or more components in dry, moist, single- or multi-layer form. Prior to application in the production process, components have to be analysed with regard to their chemical, physical and biochemical properties, such as water content, pH, chemical composition, storage requirements, *etc*.

To fulfill their function, edible coatings have to be applied to the product, have to remain on the product during storage, but should disintegrate or dissolve during cooking or consumption of the coated food product. As regards protein coatings, the decomposition process could be determined by the specific properties of the applied proteins (such as thermoplastic properties or solubility) as well as external factors, such as pH, production environment, level of protein denaturation, coating thickness or processing temperature. In view of the available research data, whey protein coatings disintegrate easily when heated [Longares *et al*., 2004].

Edible coatings have to meet a number of functional requirements. The most important functions are: satisfactory barrier properties to water, other substances and gases, solubility in water and fat, adequate color and appearance, mechanical and rheological properties, non-toxicity. Those properties are determined by the type of applied material, production method and manner of application on the food product. The type of plasticizer, the substances added to inhibit the growth of microorganisms and other functional substances may modify the properties of edible coatings [Gontard *et al*., 1993].

Soy protein is applied in the production of edible coatings due to its satisfactory functional, nutritive and nutraceutic properties [Liu, 2000]. Due to good barrier properties, soy proteins may be used in the production of multi-layer packaging which protects food mainly from oxygen migration and, consequently, inhibits fat oxidation and moisture loss. Antioxidants and substances modifying the product's taste may be added to soy coatings to modify their general qualitative properties [Kunte *et al*., 1997].

Edible coatings based on milk proteins exhibit good mechanical properties and barrier properties in respect of oxygen, lipids and aroma. Milk proteins are hydrophilic and show low water barrier properties [Chen, 1995; Krochta & de Mulder-Johnston, 1997; Miller & Krochta, 1997; Chick & Ustunol, 1998; Seydim & Sarikus, 2006]. The water barrier properties of edible coatings based on milk proteins can be improved by adding hydrophobic substances such as lipids [Shellhammer & Krochta, 1997; Perez-Gago & Krochta, 1999]. Fat substances occur in two forms in edible coatings: as laminates (where fat is a separate layer) and emulsions (where fat is evenly spread in the coating layer) [Martini *et al*., 2006].

The barrier properties of biopolymer coatings are an important parameter from the point of view of packaging functionality [Anker *et al*., 2002] and are determined mainly by coating components and the applied production methods [Matuska *et al*., 2006].

Many edible coatings may lower the product's sensory properties to an undesirable extent. The functionality of coatings may be improved by increasing the thickness of the coating layer to an imperceptible yet functional degree [Kim & Ustunol, 2001]. Another practical problem is posed by the absence of effective protection against water vapor migration which could substantially enhance the functional properties of edible coatings. Research is currently under way to improve the barrier properties of polymer coatings and increase their mechanical strength. The problem could be solved through the application of enzymes, alkaline compounds, UV radiation, plasticizers and the modification of temperature in the process of heating the coating solution. The addition of other natural polymers, such as wax, fats and fatty acids, could also modify the properties of protein coatings [Rhim *et al*., 1999].

COATING APPLICATIONS

Edible coatings are widely applied in the food processing industry. Natural coatings comprise a broad range of various protein and carbohydrate components which deliver different functions subject to the product's specific features and the anticipated properties of the final product. Edible coatings are applied to prolong the shelf-life of plant and animal products, especially in unprocessed form; they are used as packaging for ready-to-eat food, bakery products, and as carriers of food preservatives, process additives and spices [Tederko, 1995].

Protein coatings have a variety of applications in the pharmaceutical industry and are widely used to prolong the shelf life of food products. The most popular applications include collagen sausage casings, gelatine capsules for drugs and zein coatings for walnuts and candy [Irissin-Mangata *et al*., 2001]. Starch coatings are also applied in the food processing and pharmaceutical industries, mainly because they are isotropic, odour-free, flavour-free, transparent and non-toxic [Pareta & Edirisinghe, 2006].

Protein coatings containing fat (acetylated monoglycerides) are applied to coat fresh fruit (apples, citrus fruit) and dried fruit (nuts). This processing method is used to prolong the ripening period, prevent water loss, preserve their texture, flavor and aroma [Kester & Fennema, 1986; Shaw *et al*., 2002]. Casein coatings comprising sodium caseinate and vegetable oil were applied to cover chocolate products [Rice, 1994].

Cellulose derivatives are applied together with other components to produce protective edible coatings, *e.g.* double layer coating comprising HPMC (hydroxypropylmethylcellulose) and fatty acids maintains the water content of the coated product at a stable level [Kamper & Fennema, 1995]. CMC (carboxymethylcellulose)-based coatings are less permeable to oxygen than to carbon dioxide. This feature is used to prolong the ripening time of fruit (such as bananas and apples) during transport [Banks, 1984].

Dextrins are applied to coat products such as nuts and almonds to preserve their organoleptic properties and texture in storage [Murray & Luft, 1973]. Alginates are used as coatings for beef, pork, poultry and lamb carcasses. This coating method involves spraying, immersing the product in the alginate solution and gelating [Earle & McKee, 1976].

Carrageen gel and the resulting dry coatings are applied to cover meat and meat products. This type of coating minimizes moisture loss and bacteriological contamination. Carrageen coatings are used as separate packaging for the components of ready-to-eat food products in a single container [Tederko, 1995].

The product range and sensory properties of dried fruit can be enhanced by covering the products with cereal coatings containing wheat germ, oatmeal, nuts and sugar. During the coating production process, a layer of dissolved fat or oil is spread on the product which is then covered with the above components. The resulting products are characterized by high sensory attractiveness and excellent nutritive properties [Blanthorn & Labaw, 1990].

The production of spray-dried capsulated products, in particular flavors, relies on coatings which form a protective layer around a molecule. The resulting colloidal coating protects the product against the loss of flavoring substances [Tederko, 1995].

Edible coatings are also used as selective barriers which control mass exchange during processing, *e.g.* frying. Polysaccharide coatings provide an excellent barrier for fats and oils which is why they are widely applied to cover products intended for frying [Anonymous, 1997; Ogonek & Lenart, 2002]. The potential benefits resulting from the use of edible coatings in osmotic dehydration include: greater water loss, the option of preserving the product without additional processing, lower loss of added substances (colorants, nutrients, flavors), lower penetration of osmoactive substance, a lower impact of oxygen and microorganisms on the material, higher product content, more attractive appearance and a higher content of dietary fiber [Camirand *et al*., 1992].

Edible coatings are applied in active packaging because they eliminate or inhibit the growth of undesirable microorganisms in food products and due to their functional properties. Active packaging prolongs the shelf-life of food products, contributes to their attractiveness and sometimes enhances the taste and nutritive value of the coated product. Active coatings can be classified in terms of their function into the following categories [Trzcińska, 2006]: antibacterial, absorbing oxygen, releasing or absorbing carbon dioxide, absorbing ethylene, releasing ethanol, and releasing or absorbing flavor.

Antibacterial substances may be added to coating materials to control the growth of undesirable microorganisms in food. The selective action of such coatings involves the release of a specific active component during storage which interacts with microorganisms. Yet some substances may pose a consumer risk if their selective action is not determined in detail. Selective action coatings are most commonly applied to cover meat, poultry, fish, bread, cheese, fruit and vegetables [Vermeiren *et al*., 1999].

The above coatings are also applied in ready-to-eat food. These products are subjected to a complex treatment process which is accompanied by a high risk of microbiological contamination, which is why the processed products have to be cold stored. Ready-to-eat food is subject to stringent safety and qualitative requirements. Edible coatings could enhance the properties and prolong the shelf life of such products [Cagri *et al*., 2004]. Coatings may be a carrier of antibacterial compounds and/or antioxidants as well as additional substances on the product surface [Oussallah *et al*., 2004].

The minimal processing technology in the food industry uses protein coatings in view of their barrier properties to light, water vapor, oxygen, carbon dioxide and ethylene and their ability to retain the product's aromatic substances. When applied to raw fruit and vegetables after harvesting, edible coatings significantly minimize storage losses which are reported at a high level worldwide. Peeling, cutting and disintegration exposes fruit and vegetable tissue to factors which reduce their life and hygiene safety. The use of edible coatings to protect the tissue of minimally processed raw materials could substantially prolong their life [Świderski *et al*., 1999].

Edible coatings are also applied on packaging materials to enhance their barrier properties. As an example, whey coating is applied on multi-layered cardboard boxes to increase their fat barrier properties and improve their color [Rhim *et al*., 2006].

CONCLUSIONS

Edible coatings have been applied in food technology for many years. The raw materials used in the production process involve mainly natural polymers and wax. Scientists are researching new production methods to make coatings edible, safe and fully functional. According to a broad range of research findings, edible coatings may be applied to prolong the shelf-life of food products, control material exchange, improve the products' sensory properties, nutritive value and attractiveness. Edible coatings are used mainly in fruit and vegetables to prolong their ripening period during storage, they are also applied to coat meat products, nuts, almonds and a variety of other food items. Active packaging is yet another area of application of edible coatings. The shelf-life of food products can be substantially prolonged through the addition of substances which inhibit the growth of microorganisms, release or absorb selected components. Edible coatings are a promising solution to the problem of controlling water vapor permeability and may be used as independent packaging for many food products.

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POWŁOKI JADALNE – TWORZENIE, CHARAKTERYSTYKA I ZNACZENIE – ARTYKUŁ PRZEGLĄDOWY

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Wzrost zainteresowania żywnością o długim okresie przydatności do spożycia oraz wysokiej atrakcyjności sprzyja opracowywaniu nowych technologii, które pozwalają modyfikować cechy produktu i wydłużyć jego trwałość. W ostatnim czasie coraz więcej uwagi poświęca się powlekaniu żywności.