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Review

Influence of composite edible coating systems on preservation of fresh meat cuts and products: a brief review on their trends and applications

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Abstract

Development of composite edible coating systems is a new technological approach towards coating of foods to conserve their quality and safety. Edible coatings are single or multiple miscible biopolymers which significantly improve the shelf life of fresh meat cuts or products by lowering water activity (a_w), reducing lipid oxidation and met-myoglobin formation, improving product appearance in package by reducing water drips, and retention in native volatile flavours. Edible coatings can also carry functional ingredients such as antimicrobials, antioxidants, and several components/molecules which are embedded in polymer matrix expresses its barrier and surface protection properties. With these properties towards the preservation of meats, edible coating is a robust technological approach both in conventional and advanced food processing. The present article reviews the research contributions and innovations in the development of edible coating/films, and summarises the applications of different lipid, polysaccharide, protein, herbal, microbial and nanomaterials and their multi-component edible coating systems for preservation of meat cuts and products.

Introduction

Edible coating is a thin/micro layer of edible polymers with biological and chemical functions formed as a coat on food products for their preservation (Donhowe and Fennema, 1994). Generally, plant and animal sources are reservoirs of these biopolymers such as resins, oleoresins, gums, lipids, polysaccharides, proteins, and other resinous substances which are extracted and purified with appropriate processing methods and techniques from their raw sources (Kaplan, 1998; Ponce *et al*., 2008). Plant sources are extensively used in the formulation of edible coatings due to their unique and abundant levels of polyphenolic compounds which act as potential antioxidant and antimicrobial agents in the formulated coatings (Kahkonen *et al*., 1999; Miean and Mohamed, 2001; Proestos *et al*., 2005). The nature of coating should be wet and spread uniformly on the surface of food product, and have the nature to form a layer-like structure that has good physical properties (e.g., adhesion, cohesion, durability) to function effectively (Baldwin *et al*., 2011). Edible films or coatings have been studied for their abilities to retard microorganisms, moisture, oxygen and aroma barrier properties especially in the case of minimally processed foods. All these are important because edible films and coatings carry several functional compounds like plasticising, antimicrobial and antioxidant agents which could control the risk of pathogenic microflora contamination and quality loss as well as provide good keeping quality of the processed food (Cagri *et al*., 2004).

Minimally processed ready-to-cook meat products are easily contaminated, and serve as favourable substrate for foodborne pathogenic microorganisms such as *Salmonella Typhimurium, Listeria monocytogenes*, *Escherichia coli* and *Bacillus* spp. The chances of contamination by these pathogenic microorganisms continue down the processing and packaging lines (Reij and Den Aantrekke, 2004). Edible coating of fresh meat cuts is a new technological concept that has been introduced in meat processing and preservation in order to retain products with higher quality and longer shelf life without the use of any synthetic chemical preservatives (Quintavalla and Vicini, 2002). In meat cuts and products, the application of a coating or film is not only useful as a carrier of antimicrobials but can also prevent moisture loss during storage, retain

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juiciness when packed in plastic trays, reduce the rate of oxidation, and restrict volatile flavour loss and the uptake of foreign odours (Ustunol, 2009). Various types of coatings and films have been well reported to maintain the quality of meat products including fresh beef, pork, lamb, poultry and also frozen meat products (Debeaufort *et al*., 1998). The coating would act as a barrier to water and oxygen, thereby reducing purge, colour deterioration and aroma deterioration (Falguera *et al*., 2011). Oxidation is responsible for deterioration processes mainly because it induces change in colour to the fats (Gray *et al*., 1996). Edible coatings behave like a shield to control the atmosphere and restrict the transfer of water, gasses (O_2, CO_2) and escape of aromatic compounds, thus preventing quality changes (McHugh *et al*., 1993). Recent studies on the preservation of flesh foods by the application of external coating reveal that there is no doubt that edible coatings could substantially improve the quality of meat cuts (Coma, 2008). Furthermore, the meat and poultry industries could well benefit from the use of certain biopolymers in the development of films and coatings. This overview thus discusses the advantages of edible coatings/films in the preservation of meat and meat products from past to present ideologies, and summarises the research findings on the effectiveness, recent advances and future prospects of edible coatings.

Composite edible coating systems based on carbohydrates

Starches and their composite coatings

Starch is composed of amylose and amylopectin as structural units, and primarily derived from cereal grains, potatoes, tapioca and other plant sources. Starch has wide range of coat-forming applications in the preservation of fresh and frozen retail meat cuts (Pagella *et al*., 2002). Coatings/films made from starch and allied components almost resemble the characteristics of films made from synthetic polymer i.e., semi-permeable to carbon dioxide (CO_2), and resistant to passage of oxygen (O_2). Starch films/coatings are also eco-degradable, toxic-free, colourless, odourless and tasteless. Starch-based coatings have been used to extend the storage quality of muscle foods by reducing dehydration, oxidative rancidity and surface browning (Ruban, 2009). With these unique and extended features, starch-based films/coatings play an important role in the preservation of meat cuts (Bertuzzi *et al*., 2007). Films made from rice and pea starches which are rich in amylase have been noted as good oxygen barriers and perform better than films made from proteins. Films made with extruded hydroxypropylated high amylose starches have been used to wrap frozen flesh foods, and they are flexible, impermeable to oxygen, resistant to oil, heat-sealable and also soluble in water (Lourdin *et al*., 1995). These films not only protect meat products during frozen conditions, but also dissolve during thawing and cooking. Since the water activity (a_w) is critical for microbial, chemical and enzymatic activities, studies have shown that these films could resist the migration of moisture into the meat during storage (Rindlav-Westling *et al*., 1998). For example, edible starch-based films could retard microbial growth by lowering the a_w within the package, thereby reducing drip loss of meat products and binding water that otherwise would be available for microbial growth (Swinkels, 1995). Mehyer *et al*. (2007) inoculated mixed combination of *Salmonella* into the chicken skin and coated with pea starch incorporated with trisodium phosphate (TSP); their observations concluded that the films exhibited good adhesion, cohesion and antimicrobial activity. Maizura *et al*. (2010) constructed films with good mechanical barrier and effective against *Escherichia coli* which are made from partially hydrolysed sago starch and alginate with lemon grass oil and glycerol.

Alginates and their composite coatings

Alginates are the primary bio-macromolecules extracted from brown seaweeds, and extensively used to coat fresh and frozen meat cuts (Gacesa, 1998). Alginates are sodium salts of alginic acid, which is a linear linked polyuronic acid containing complex structure of poly-β-D-manopyranosyluronic acid blocks and poly-α-L-glucopyranosyluronic acid blocks (Ertesvag and Valla, 1998). Generally, alginates form strong and brittle coatings with low range of water resistance. However, alginates react with polyvalent metal cations; in particular calcium ions, to form water insoluble polymers (Goh *et al*., 2012). Two-step procedures are used to coat meat, poultry, and sea foods with alginate-based coatings. Application of aqueous sodium alginate solution on targeted foods by dipping and spraying are the two ways followed by application of calcium salt solution to induce effective gelation on formation of films with more water resistance than pure alginate films (Juck *et al*., 2010). Several types of calcium salts have been employed to make alginate films/coatings. However, calcium chloride ($CaCl_2$) yields stronger alginate coatings when compared with calcium gluconate, propionate or nitrate (Benavides *et al*., 2012). Millette *et al*. (2007) observed a reduction in *Staphylococcus aureus* growth in ground beef and sterile beef muscle slices covered with nisin-palmitoylated alginate films. Marcos *et al*. (2007)

tested the antimicrobial effect of biodegradable films containing enterocins against *Listeria monocytogenes*, and found that air-packaging with alginate films containing 2000AU/cm^2 of enterocins effectively controlled the *L. monocytogenes* population. Recent studies reported a reduction in dehydration of coated frozen lamb muscle prior to freezing by successive immersions into aqueous solutions of sodium alginate and glycerine (Koushki *et al*., 2015). Fresh whole beef muscles resulted in good storage quality when the muscle surfaces were inoculated with microorganisms and coated with aqueous solution of sodium alginate containing essential oils (Oussalah *et al*., 2006). Earle and McKee (1985) were awarded a patent for a spraying method applied on fresh meat coating process which contained sodium alginate-oligosaccharide and calcium chloride ($CaCl_2$) thickening agent as key components. Siragusa *et al*. (1992) observed that organic acids added to calcium alginate gels and immobilised on lean beef tissue reduced the *L. monocytogenes* population significantly, more than acid treatment alone. Cutter and Siragusa (1997) treated ground beef with calcium alginate incorporated with nisin, and observed suppressed growth of *Brochothrix thermosphacta* to undetectable levels. Keshri and Sanyal (2009) dipped buffalo meat patties at the end of the broiling process in alginate solution with added preservatives. The meat patties coated with alginate significantly decreased the overall shear forces, thiobarbituric acid and tyrosine values, and total plate, psychrophilic and yeast and mould counts.

Carrageenan and its composite coatings

Carrageenan is a material extracted from red seaweed, and a complex mixture of several water-soluble galactose polymers (Mangione *et al*., 2003). Three principal carrageenan fractions have been classified based on different sulphate ester contents and distributions of 3, 6-anhydro-α-D-galactopyranosyl residues; κ, λ and ι-carrageenans. κ-carrageenan has the least negative charges per disaccharide and highest tensile strength when compared with λ and ι-carrageenans (Campo *et al*., 2009). Wu *et al*. (2002) treated beef patties with wheat gluten, soy protein and carrageenan, and refrigerated for over three days. After three days, no difference was found in moisture loss between individual film-wrapped patties and unwrapped patties. However, carrageenan-coated patties exhibited reduced TBARS (thiobarbituric acid reactive substances) values and hexanal values as compared to control. Tyburcy and Kozyra (2010) studied different emulsion formulas (0.5 or 1% w/w κ-carrageenan and 5 or 10% w/w glycerol), and found that κ-carrageenan concentration had a significant effect on the amount of emulsion adsorbed on the sausage surface but little influence on the barrier properties. Panyathitipong and Puechkamut (2010) investigated carrageenan's' role on functionality and physical characteristics of surimi emulsion gel, and found that increased carrageenan's concentration improved the stability, water holding capacity and hardness of the gels. In depth, structural and morphological studies concluded the formation of smoother and typically compact gels with carrageenan. All the above studies described composite coatings induced with antioxidants, antibiotics and other biologically active compounds to improve the quality and microbiological safety of meat and meat products, where traditional methods failed to provide.

Chitosan and its composite coatings

Chitosan (a linear bio-polysaccharide), is derived from the deacetylation of chitin (β-1,4-D-glucosamine) which is predominantly found in shells of crustaceans (Whistler and Daniel, 1985). It is a high molecular weight cationic polysaccharide that exhibits antibacterial and antifungal activity with film-forming nature (Kittur *et al*., 1998). Vast information has been reported about chitosan's potential as a food preservative which has been evaluated either *in vitro* or through direct application on various food models. Chitosan-based coatings/films have good mechanical properties, selective gas permeability (CO_2 and O_2) and antimicrobial activity (Guo *et al*., 2013). However, their applications are limited by their nature of high water vapour permeability. Good film/coat forming capacity of chitosan greatly protects and improves the quality and shelf life of fresh and processed foods (Dutta *et al*., 2009). With a unique mechanical and barrier properties, a single chitosan coating has been successfully applied on processed silver carp fish and roasted ready-to-eat beef. Kanatt *et al*. (2008) worked on minced lamb meat and pork cocktail salami coated with chitosan and mint mixture, and those coated samples were observed with reduced food spoilage, pathogenic microflora and oxidative rancidity. Chatli *et al*. (2014) worked on composite starch-chitosan films supplemented with nisin and cinnamaldehyde, and observed the films' effect on the quality and shelf life stability of raw chevon chunks. They found that the microbial and sensorial attributes (colour, odour, texture and overall acceptability) were better in chitosan film packed samples than the control samples throughout the storage. Guo *et al*. (2014) investigated meat surfaces coated with polylactic acid, edible chitosan acid solutions with or without incorporating lauric arginate ester, sodium lactate and sorbic acid against *Listeria innocua*, *L. monocytogenes* and *Salmonella Typhimurium*. Their results revealed that film with added additives shown positive effect in the ready-to-eat meat.

Agar and its composite coatings

Another material derived from polysaccharide is agar which has multiple applications in food processing and preservation. Several uses of agar as gelling and thickening agents in foods attracted the researchers to utilize agar as edible coating material. Agar is derived from sea weeds with great gelling and film forming nature (Phan *et al*., 2005). Agar coatings with combination of antibiotics and other chemical compounds have extended the shelf life and keeping quality of poultry and beef (Phan *et al*., 2008). Recently, a research has shown that application of agar coatings (added with bacteriocins and other chelating agents) on poultry product surfaces successfully inhibited the *S. Typhimurium* count (Natrajan and Sheldon, 2000). Present research on impact of agar in the preservation of meats and allied products are still limited, and its role in coating meat products is still under investigation.

Celluloses and their composite coatings

Cellulose is a complex organic polysaccharide chiefly found in plant cell walls. Celluloses are usually not digested in human intestines because of its complex polymer structure, and due to the absence of human intestinal cellulases. Due to its great physical and mechanical properties, celluloses have been extensively used in the manufacturing of edible films with good barrier properties like water solubility, resistant to fats and oils, and also flexible in nature (Jia *et al*., 2014). Researches have demonstrated that improved cellulose-based films applied on muscle foods could reduce the oil uptake while deep fat frying, and reduce moisture loss when applied as glazes for poultry (Balasubramaniam *et al*., 1997). According to Nguyen *et al*. (2008) *L. monocytogenes* count in processed meats were notably inhibited with cellulose films containing nisin. Methyl celluloses have wide range of applications in red meat processing because of its firm gelling nature (Donal and David, 1995). Cellulose casings are widely used by the meat processors in the manufacturing of ready-to-eat products, including frankfurters, sausages, bologna and other meat products which are thermally processed. Cellulose casings are designed to be used and removed easily from the product, and the casings could also be easily disposed and degraded. This type of cellulose casings is beneficial for the regeneration/recovery of cellulose (Parth, 1960; Shiner, 1961; Judd and Talty, 1979). Melo *et al*. (2012) investigated and obtained positive results on cellulose acetate-based coatings incorporated with natural antimicrobial agents against spoilage and pathogenic microorganisms, and pH and colour deterioration of chicken breast cuts at refrigerated temperature.

Gums and derivatives

Gums are complex polysaccharide compounds secreted by plant materials naturally or by specific mechanical extrusion process. Gums, including exudate gums (Arabic, tragacanth and karaya gums), seed gums (locust bean and guar gums) and microbial fermented gums (xanthan and gellan gums), have been extensively used in edible coating of foods (Verbeken *et al*., 2003). The chemical structure of plant exudate gums are complex and vary depending on the plant source and age (Mirhosseini and Amid, 2012). Rakshit and Ramalingam (2012) have successfully inhibited five spoilage and disease causing bacteria (*Escherichia coli*, Proteus mirabilis, *Staphylococcus aureus*, Enterococcus faecalis and *Bacillus* cereus) in meat and fish coated with gum acacia (incorporated with garlic and cinnamon as alternate preservation method). Stypula (1989) have been awarded a patent in development of barrier coating with combination of starch, methyl cellulose and xanthan gum with special reference of macerated beef and chicken. Bouaziz *et al*. (2015) studied the effect of enzymatically hydrolysed, low molecular weight oligosaccharides of almond gum on beef meat preservation, and found significant difference in lipid oxidation and inhibition of microbial growth on ground beef samples. The exact applications of gums on meat preservation are not yet well understood. Therefore, deeper investigation is needed on the suitability and flexibility of gums on physical and mechanical properties of meat and meat products.

Protein-based composite edible coating systems

Proteins and their mixtures have been widely used as edible film and coat forming agents because of their unique nature and well defined coat-forming capability. Proteins can form good coat/films while their physical properties will change with pH, temperature and other proteins within the food matrix (Inada *et al*., 1995). It is important for the food manufacturers and researchers to carefully study the proteins' characteristics when designing protein-based edible films/coatings. Additionally, food processors have to clearly label on their products about allergens that may be associated with the protein coatings (Korhonen, 2002). Edible coatings that hinder mass transfer of oxygen, carbon dioxide, water vapour or aromatic compounds represent the majority of applications investigated for protein-based edible coatings. Protein-based coatings also have the potential to improve the glossy appearance of foods and protecting them from microbial spoilage. Such applications have been investigated for protecting meat products from spoilage microflora.

Collagen/gelatine and their composite coatings

Gelatine is a translucent, brittle and flavourless edible proteinaceous substance found in nature. It is actually a partially denatured product of collagen which is abundantly present in animal tissues, and can be used to lessen both oxygen and moisture migration, and as an antioxidant carrier when used as edible coating. In various meat products, purge was successfully reduced with the use of gelatine coatings (Prabhu *et al*., 2004; Antoniewski *et al*., 2007; Herring *et al*., 2010). When a gelatine coat was applied on pork, poultry and fish products, it was found that beef showed a reduction in colour deterioration (Gennadios, 2002). Oxidation of lipids, which is significantly correlated to changes in aroma and flavour was minimised with gelatine coatings applied on pork, poultry, and fish products (Antoniewski and Barringer, 2010). Li *et al*. (2015) fabricated gelatine-laponite composite films to study the freshness and physical properties of meat during the storage. In their investigation, they found improved antioxidant activity, gas and water vapour barrier properties, gel strength, mechanical properties, water vapour permeability and water solubility of the edible coat. The application of gelatine solution on the surface of a meat product requires heat which permits the gelatine to go into solution (Djagny *et al*., 2001). Arvanitoyannis *et al*. (1998) found that good results were seen when the solution contained gelatine ranged from 15-55% (w/w) with 30% plasticisers. These ranges were especially favoured in terms of adherence to the meat surface. Liu *et al*. (2007) manufactured sausages using gelatine/sodium alginate blend casings containing both corn oil and olive oil at 2.5%, and found better oxygen barrier properties as compared to sausages manufactured using pectin containing the same concentration of emulsified oils.

Collagen also has found commercial success as a protein coating with good oxygen barrier property, even though it is not a good moisture barrier. Collagen coatings have shown reduced amount of purge lost in meats (Villegas *et al*., 1999). Farouk *et al*. (1990) found that less purge in beef round steaks with a collagen coat, which were packed in different types of packaging methods like vacuum-packaged, tray-packaged with PVC and frozen/refrigerated products stored for a week. When compared to plastic wraps, collagen wraps showed little difference in moisture vapour transmission rate and strength.

Milk proteins and their composite coatings

Casein, whey protein and combinations of both are generally termed as milk proteins. They can result in different film forming properties depending on the commercial source and method of extraction (Boyd *et al*., 1973). Whey protein isolate films are good barriers to gaseous exchange but its hydrophilic nature limited the moisture barrier ability of the films/coatings (Sabato *et al*., 2001). Several researchers have investigated the properties and influence of milk protein-based films/coatings on fruits and vegetables and other dairy foods, but there is limited research addressing the application of milk protein-based films/coatings on fresh meat cuts and products. Recently, scientists have demonstrated that when casein was mixed with water and glycerol and left to dry, a water-resistant, flexible, film like material was formed. This film did not only lock moisture in some foods, but also was found to be a durable barrier to invasion of foreign substances (Siew *et al*., 1999). Oussalah *et al*. (2004) applied combination of milk proteins and essential oils on beef muscle slices to control the growth of pathogenic bacteria and increase the shelf life during storage at 4°C. During the investigation, lipid oxidation potential of meat was evaluated and concluded that the films stabilided the lipid oxidation in the beef muscle. Recently, Zinoviadou *et al*. (2009) studied the physicochemical properties of whey protein isolate films containing oregano oil to coat fresh beef. In their study, they enumerated the antimicrobial activity of whey protein isolate films incorporated with oregano oil against total microflora, pseudomonads and lactic acid bacteria which were completely inhibited.

Cereal/pulse proteins and their derivatives

Some of the purified cereal and pulse proteins have unique and effective coat/film forming capability. Among the pulses, soy proteins are one of the well-known and widely used functional and nutritional ingredients with polymeric nature. Soy protein biopolymer coatings exhibited good oxygen barrier property on storage of precooked beef patties and cut raw beef; the same experiment also demonstrated that lipid oxidation and moisture loss were effectively inhibited (Penta-Ramos and Xiong, 2002). Dawson *et al*. (2002) investigated the growth patterns of *L. monocytogenes* in bologna coated with soy protein coatings enriched with lauric acid and nisin. In their experiment, they observed the complete elimination of *L. monocytogenes* cells in the coated samples.

Gluten is one of the cereal proteins chiefly present in wheat with complex combination of polypeptides (gliadin and glutenin) with a little carbohydrate and lipid components (Nishinari *et al*., 2014). Plasticisers are undoubtedly required to increase the flexibility while casting gluten-based films/coatings due to their more brittle nature. These films are high in water permeability but are good barriers to gaseous exchange (Brandenburg *et al*., 2014). Zein is a cereal protein abundantly present in corn and soluble in aqueous alcohol. It gives glossy appearance and grease-resistant surface upon drying, and is insoluble in water except at very low and high pH levels (Stuchell and Krochta, 1994). High glass appearance, rapid drying rate and increased stability of zein made itself as alternative agent for shellac. Recent research explained the possibilities of enzyme degradation of proteins released from the flesh foods during the storage in spite of its advantages (Artharn *et al*., 2007). Foods wrapped in protein-based films might have allergens and could be harmful especially to individuals with food allergies associated with milk, egg, peanut, soy bean or rice proteins. Therefore, more researches will be needed on these issues in the development of edible coatings based on proteins.

Oilseed proteins and their derivatives

Oilseed proteins play a limited role in edible coating of foods. Among the oilseed proteins, globulin fractions isolated from soybeans and peanuts are often used to form films/coatings on foods. Researchers have developed a process where oilseed proteins are used to stabilise dehydrated meat (Moon and Li-Chan, 2007). Coated meat products exhibited good texture and rehydrated characteristics which were maintained without any notable alterations in the meat flavour. Micro encapsulation with soybean proteins has also been discussed by researchers (Gan *et al*., 2008). However, the functionality of soy protein or peanut protein-based edible coatings on other food products has yet to be explored. More findings are needed in relation to the oilseed proteins behaviour towards the casting of potential coatings/films of fresh meat cuts and products.

Lipid-based composite edible coating systems

Waxes and their composite coatings

Waxes have been exponentially used worldwide from the 19th century as coatings to protect fresh fruits and vegetables (Baldwin *et al*., 1995). Carnauba, bees and paraffin waxes are commonly used to preserve meat cuts (Tharanathan, 2003). In the 1950's, frozen and fresh meats were coated with microcrystalline wax derived from petroleum in the United States of America (Embuscado and Hubber, 2009). In general, wax coatings have been shown to have great resistance towards moisture and gas permeability when compared with any other lipid biopolymers (Hagenmaier and Shaw, 1992). Waxes are good lipid matrix to carry various predefined functional compounds to enhance the physical and biological characteristics of the resulted films/coatings. Few researches are available regarding the waxes as protective coatings for meats. Gogus *et al*. (2004) studied and observed the reduced rate of Gram-positive and negative, *S. Typhimurium* and *Pseudomonas* species (spoilage flora commonly found during the evisceration of carcasses) in dressed whole chickens coated with the wax added with nisin and yoghurt prior to freezing. In another investigation, researchers observed the limited moisture loss in wax-coated frozen birds when compared with corn oil and lard-based coatings, but not as great as synthetic polymer bags (Morillon *et al*., 2002). Koonz and Ingle (1943) have received a patent for the development of simple, cost-effective, economical and readily applicable coating method to protect the hams and green hams. In this process, researchers discovered the combination of amorphous wax-rubber, resin coatings that can form a seal around the food which is substantially impervious to water, brine, water vapour and gaseous exchange, and flexible at temperatures below freezing, and resistant to the freezing expansion. These coatings are easily peeled off and can be reused in infinite number of types. Wax film/coat forming solution is more useful due to its complex network to carry biological active agents like antioxidants, antimicrobials and other composite functional materials. The unique characteristics and applications make wax and its derivatives as iconic agent in edible coating/film of meat cuts and products.

Fats and their complex coatings

Coating foods with fat is a well-known traditional method called 'larding', which started in England in the 16th century (Gibbs *et al*., 1999). Fats and oils have the capability to form a thin coat with unique sealable nature on the surface of the food thus forming a barrier between the food and its external environment. Few researches are available however, regarding the effectiveness and physical barrier properties of fats and oil coatings on meats.

Preservation characteristics and validation of coating process was standardised and optimised by various researchers based on the desired objectives set in the processing of meat cuts and products (Cutter, 2006). Substantial dehydration has been prevented in frozen meats, poultry and fish coated with animal fat/vegetable oil blended with emulsifiers, water and preservatives (Nassinovitch, 1997). Freeze-dried meats showed significant reduction in moisture uptake when coated with liquefied fats at 52°C to 79°C (Guilbert *et al*., 1995). The use of long chain saturated fatty alcohols or fatty acids were well suggested by researchers to control moisture loss at freezing temperatures (Anderson, 1960). Reportedly, better results in moisture loss were obtained in frozen meats coated with ice before applying the fatty films/coatings. Hydrophobic nature of the film/coating is due to the intermediate hydrophilic layers formed between the film and the meat surface which attracted polar groups of the fatty acid films/coatings (Fernandez *et al*., 2007). Vargas *et al*. (2011) worked on casting of chitosan and sunflower oil edible films to preserve the pork meat hamburgers. In their work, they found that the incorporation of sunflower oil to the chitosan matrix led to a reduction in metmyoglobin content as compared to control samples coated with pure chitosan films.

Glycerides and their composites

Glycerides are esters formed from glycerol and fatty acids, or more precisely known as acylglycerols. Three hydroxyl groups in glycerol can be esterified with one, two or three fatty acids to form mono-, di- or tri-glycerides, respectively. Most of the vegetable oils and animal fats are tri-glycerides, but are denatured by lipases into mono-, di-glycerides and free fatty acids (Fryer and Weston, 2013). Acetoglycerides are made by acetylation of glycerides i.e. converting glycerides into mono- or di-acetylated products by replacing a number of fatty acids in the glyceride. Generally, acetoglycerides are alpha, alpha-beta, alpha-alpha and beta types under normal methods of production. Both glycerides and acetylated glycerides have been used as effective coatings in meat and meat products. Acetylated glycerol monostearate coatings have little more permeability to water vapour than polyamide, ethylcellulose, and polystyrene films, and significantly more permeable than cellophane and polyethylene films (Bourtoom, 2008). When it comes to oxygen barrier capability, acetylated glycerol monostearate coatings have less permeability to oxygen than ethyl cellulose and polystyrene films. Excellent water retention was observed in coated meat foods even though coatings have high impermeability to oxygen which results in meat discoloration during storage (Lin and Zhao, 2007). Glycerides and acetoglycerides in coating meat cuts and products are limited and little information regarding the edible coatings of meat products are available in the literature. Therefore, the potential applications of glycerols require more technological development before its coatings in meat foods can be further commercialised.

Composite edible coating systems based on herbs

Herbal components are biological functional materials identified, screened and extracted from plant materials by a series of processing methods. Plant exudates, gums, resins, essential oils and other extracted compounds containing various functional groups are generally termed as herbal-based components. These functional compounds could act as anti-microbial and anti-oxidant agents which are further used with biopolymers to coat the foods. Some of these plant-isolated compounds have unique coat-forming nature due to their polymeric ability.

Essential oils and their composites

Essential oils (EOs) are aromatic and volatile extracts obtained from aromatic and medicinal plant materials including flowers, buds, roots, bark, and leaves by means of various extraction methods like expression, fermentation and steam distillation. EOs from oregano, rosemary, thyme, clove, balm, ginger, basilica, coriander, marjoram and basil have shown great ability in microbial growth retardation when used in meat cuts and products (Burt, 2004; Ouattara *et al*., 2008). Researchers have examined the use of aromatic phyto-chemical preparations with dual functionality against microbial spoilage and lipid oxidation in meat and meat products; particularly they observed the role of EOs in meat preservation. These non-phytotoxic volatile compounds are safe as food additives and given the "generally recognized as safe" (GRAS) status, which results in higher consumers' acceptability (Sacchetti *et al*., 2005). According to Skandamis and Nychas (2001), delayed glucose and lactase consumption and reduction in proteolysis was observed in minced meat mixed with various concentrations of oregano EO under aerobic conditions (modified atmosphere) at 5°C. Matiacevich *et al*. (2015) characterized the physical, antimicrobial and sensorial attributes of fresh chicken breast fillets coated with the composite of alginate-thyme oil-propionic acid. Researchers also found that coating increased the shelf life by 33% while yielding the lowest dehydration rate. Fresh chicken liver was coated with EDTA and oregano EO, packaged under modified atmosphere packaging and stored under refrigeration. Researchers observed that the shelf life of the chicken liver was substantially increased by three folds when compared with control and standard samples (Hasapidou and Savvaidis, 2011). Jayasena and Jo (2013) showed that plant-derived EOs have remarkable antimicrobial potency against spoilage and pathogenic microorganisms in meat and meat products. Above evidences provide more attention towards the development of EO-mediated edible coatings to preserve fresh meat cuts and products. However, the research on this area is still in its infancy and more studies on the application of EOs in the development of edible coatings are henceforth warranted.

Herbal extracts and their derivatives

Plant extracts are natural, biological functional components extracted with various extraction techniques. Extracted plant components have unique antimicrobial, antioxidant, and biologically safe characteristics which make them most successful as alternative to the use of synthetic chemical agents in food preservation. The addition of natural preservatives derived from plant extracts as a way of increasing the shelf life of food products has become ideally popular in recent decades. Plant-derived components exhibit effective control on foodborne pathogenic microflora (Gutierrez *et al*., 2009). Few research studies demonstrated that *L. monocytogenes* was successfully inhibited in turkey frankfurters coated with soy protein edible films containing plant extracts and nisin (Theivendran *et al*., 2006). Ozvural *et al*. (2016) compared the impact of three different techniques i.e. direct addition, edible coating and encapsulation, on hamburger patties with green tea extract. Wong and Kitts (2002) studied the effect of herbal pre-seasoning (ginseng and garlic herbs) on microbial and oxidative changes in irradiated beef steaks. In their investigation, they found the reduction in psychrotroph count in both non-irradiated and irradiated steaks. Many researches have been focused on the applications of plant extracts in the development of edible coatings worldwide on account of its potential health benefits as well as low risk management in the preservation of meat cuts.

Edible coatings derived from microorganisms and microbial products

Bacteriocins

Bacteriocins are antibacterial peptides produced by lactic acid bacteria. These agents are generally heat-stable, apparently hypoallergenic and readily degraded by proteo-lytic enzymes in the human intestinal tract (Lade *et al*., 2005). Some of bacteriocins such as pediocin and lacticin have been developed for possible approval and use in food preservation. Nisin remains one of the most commercially important bacteriocin because of its potentially long track of safe use in foods and documented as effective agent to inhibit the important Gram-positive foodborne pathogens and spoilage microorganisms (Arauz *et al*., 2009). Nisin, produced by *Lactococcus lactis*, and pediocin produced by the *Pediococcus acidilactici* have been demonstrated by several researchers to be active against *L. monocytogenes* and other Gram-positive bacteria on meat surfaces when applied together with edible coatings (Ming *et al*., 1997). Samelis *et al*. (2005) evaluated the inhibition of *L. monocytogenes* introduced on sliced cooked pork bologna dipped in solution contained nisin with or without organic acids or salts before vacuum packaging and stored at 4°C for 120 days. Cutter *et al*. (2001) demonstrated the retention of nisin activity when introduced into the plastic films. Processing conditions used to produce the films did not affect the antimicrobial activity of nisin. Economou *et al*. (2009) investigated the shelf life extension of fresh chicken flesh treated with nisin-EDTA in combination with MAP. In their research, the antimicrobial treatments with MAP resulted in an organoleptic extension of refrigerated, fresh chicken meat by approximately 13-14 days with acceptable odour even up to 24 days. Woraprayote *et al*. (2016) discussed and explored the utilisation of bacteriocins produced by lactic acid bacteria as natural preservative for fermented meat products. They also discuss the passive and active utilisation of bacteriocins in meat preservation. Bacteriocins are amphiphilic peptides susceptible to adsorption on food ingredients and proteolytic degradation, which may limit their use as preservation agents. More than 80% of the added bacteriocin is adsorbed into the muscle protein, but the activity of the protein-bound bacteriocin still remains to be assessed.

Enzymes

Enzymes are complex polypeptides produced from living cells with biological functional properties which are suitable to be utilised as food preservatives. Due to health concerns, producers are now particularly interested towards the use of enzymes as bio-preservatives in food packaging and preservation. Moreover, in most cases, these antimicrobial polypeptides were directly incorporated into meat products, and also sometimes used with the edible coatings as effective antimicrobial agents. Nattress and Baker (2003) controlled the growth of naturally contaminated lactic acid bacteria grown in the presence of acetate and *Brochothrix thermosphacta* with mixture of lysozyme and nisin at 3:1 (w/w) applied on surfaces of pork loins. However, Mastromatteo *et al*. (2010) observed the enzymatic coatings decreased the growth of *L. monocytogenes* in ostrich patties below the official limit of the European Union. Researchers studied the synergic antimicrobial activity of lysozyme, nisin, and disodium-EDTA against *L. monocytogenes* and meat-borne spoilage bacteria in ostrich patties, packed under controlled and vacuum conditions. Ntzimani *et al*. (2010) investigated the semi-cooked chicken flesh coated with combined application of EDTA, lysozyme, rosemary and oregano oils for their potentiality towards inhibition of microorganisms stored at 4°C under vacuum packing conditions. In their study, they observed that the shelf-life extended to 7-8 more days when compared to the untreated samples.

Edible coatings based on organic acids

Organic acids have shown wide ranging applications in the preservation of meats, with their unique distinctive use in food preservation leads to the innovations of biologically safe edible coatings/ films. Organic acids are marked as antioxidants and antimicrobial agents alone and have amended when induced into the polymeric network of edible coatings/ films. Siragusa and Dickson (1993) added organic acids (lactic acid and acetic acid) to calcium alginate gels and immobilised on lean beef tissue inoculated with L. monocytogenes, *Salmonella Typhimurium*, and *E. coli*, and observed reduction in the the targeted microbial count significantly more than did acid treatment alone. Syed Ziauddin *et al*. (1996) sprayed acetic acid, lactic acid and the extracts of ginger, garlic and onions alone or in combination with sodium chloride on meat cuts (beef, mutton) and chicken carcasses, and found that the shelf-life of beef cuts was longer than that of mutton and chicken cuts while colour, odour and other sensorial parameters were in gratifying manner. Ouattara *et al*. (2000) developed and coated bologna and cooked ham with chitosan edible films incorporated with acetic acid and propionic acid with or without the addition of lauric acid or cinnamaldehyde. The treated samples were observed with potential reduction in microbial count in vacuum packed meat products. Cagri *et al*. (2001) developed the whey protein-based edible films containing p-aminobenzoic or sorbic acids. In their research, they assessed the films ability towards the inhibition of L. monocytogenes, *E. coli*, and *Salmonella Typhimurium*, and mechanical properties of edible films like water vapour permeability, tensile strength and elongation at break point were also assessed. Research findings regarding the ability of organic acids as antioxidant and antimicrobial agents play a key role in construction of edible coatings/ films to extend the keeping quality of fresh meat cuts and products.

Complex edible coating systems

Edible films and coatings may consist of a blend of polysaccharides, protein, and/or lipids, enzymes, bacteriocins, and other bio-edible components. This approach enables the utilisation of distinct functional characteristics of each compound. With reference to the literature, the main objective of producing films from biopolymer blends is to improve the permeability characteristics and mechanical properties as dictated by the need of a specific application. The association among the polymers/components can be achieved through blending, extruding, laminating, or coating with other polymers with desirable properties. Xu *et al*. (2005) blended waxy and regular corn starch with chitosan in order to overcome these shortcomings. Their study on blending of biopolymers explained that the blended films had higher tensile strengths, elongation at break and decreasing water vapour transmission rates with increasing starch to chitosan ratio. Baranenko *et al*. (2013) studied and investigated the effect of composition and properties of various multi component edible coating systems on microflora of meat and meat products. In their work, they used various multicomponent combinations like organic acid, chitosan, gelatine, distarch glycerol, wheat fibre, sodium alginate and guar gum as composite edible coating materials. Multicomponent edible coatings may act superbly with multiple component effects in fresh meat cuts. Research in this area is however still limited and there is a need to overcome difficulties associated with preservation of meats which are chiefly influenced with chemical and other highly risk-oriented synthetic preservatives.

Nanocomposite edible coating systems

Nanotechnology applications in food processing and preservation, especially in coatings/films forming technologies remained unexplored due to various limitations and complications. Their applications in agriculture and food sector are relatively recent, when compared with their use in drug delivery and pharmaceuticals (Sanguansri and Augustin, 2006). Researches in the applications of nanoparticles and nanofibers in the construction of edible coatings/films are limited because of several obstacles and health hazards associated with nanomaterials interaction with human body (Marambio-Jones and Hoek, 2010).

Silver nanoparticles or silver zeolite (approved by FDA for food use) are good examples because of its unique broad spectrum antimicrobial activity (Sondi and Salopek-Sondi, 2004; Li *et al*., 2010). Silver nanoparticles are lethal to numerous strains of bacteria, fungi, algae, and possibly some viruses (Kim *et al*., 2007; Shahverdi *et al*., 2007). Bio-edible polymers used for the formation of coats/films which have direct contact with the foods can be doped with nanomaterials to increase the functional stability of the coats/films which are further used to preserve food products for long time (Sothornvit *et al*., 2009). Rhim *et al*. (2006) prepared four types of chitosan-based nanocomposite films by using a solvent-casting method. In their study, they incorporated unmodified montmorillonite, organically modified montmorillonite, nanosilver, and silver-zeolite to chitosan polymer matrix. Among the four types of nanocomposite films, nanosilver exhibited significant range of antimicrobial activity. Ramachandraiah *et al*. (2014) discussed the nanotechnology applications in meat packaging. In their view, there is possible impact on revolutionary changes in meat packaging developed by nanomaterials. In the case of meats/flesh foods, the development of nanocomposite edible coatings is in base level because meats are highly perishable, and penetration and release of nanoparticles into the inner tissues is not yet well understood. More research is therefore needed in the development of nanocomposite edible coatings and their construction. Physical and biological properties of such coatings can be studied with appropriate models. The food safety measures in consumption of such foods must be determined clinically since studies/research on the interaction and impact of nanomaterials with the human body are not yet clearly and conclusively determined.

Future trends and advances

Edible coatings are considered as eco-friendly technology for preserving fresh cut meat products, assuring their quality as well as prolonging their shelf life. Effective applications of edible coatings need to concentrate on the stability of the component, concentration on the surface of the product, the bioavailability, and the gradual release of the component and its functionality. A challenge for the use of edible coatings is their compatibility, potentiality with other advanced, emerging technologies like high pressure processing, pulsed electric field processing, ultrasound processing, microwave radiation, and gamma radiation, and how the edible coating technology itself supports its potentiality and safety is also a question that warrants further investigation. Another important aspect is the reaction of complex edible coatings with the innate enzymes and metabolites of certain food product which may cause several changes in view of quality and safety. The discovery of natural antimicrobials and nanomaterials is essential in investigating newer technologies for the formation of safe effective edible coatings and films. For example, nanomaterials when used with edible coatings would be released into the food and raise health concern. Research in nanotechnology in edible coating system is necessary to implement appropriate measures to achieve successful formation of safe nanocomposite edible coatings. The research in this area is not yet well understood but present and future things in edible coating systems may adopt innovations in nanotechnology. Advance research is therefore required to overcome the limitations and optimise the formulations in this field. Future researchers have to concentrate on the capacity of the edible coating matrix to hold or gradually release biological active components and nanomaterials, their formulations to support the matrix, chemical changes occuring at molecular levels with the use of complex edible coatings, reaction of native food enzymes with matrix of coating and other secondary metabolites.

Conclusion

Over the past decades, multiple types of edible coatings have been used to preserve meat cuts and products. Several edible biopolymers have also been widely investigated for the coating/film formation. However, majority of these edible coating systems have certain limitations and have not yet received substantial industrialisation/commercialisation, and consumer acceptance. Further investigation on nano- and bio-components, new concepts in bio-polymer network, and approaches to develop effective films/coatings to preserve flesh foods including meat cuts, products and eggs are therefore warranted. Involvement of bio- and nano-technology in the development of edible coatings and films is a hope to achieve our goals to preserve meats as well as eggs by smart packing with coating system as an alternative for traditional preservation technology.

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