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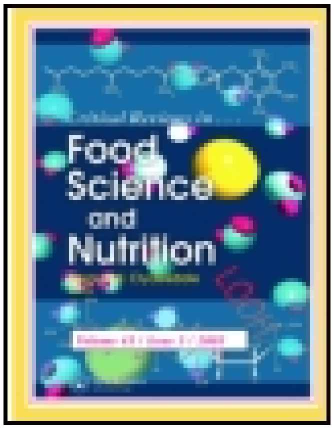

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Comprehensive Review on Application of Edible Film on Meat and Meat Products: An Eco-friendly Approach

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Comprehensive review on application of edible film on meat and meat products: An eco-friendly approach

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Abstract

The functions of packaging materials are to prevent moisture loss, drip, reduce lipid oxidation, improve some of their sensorial properties (colour, taste and smell) and provide microbial stability of foods. Edible films can be made from protein, polysaccharides and lipids or by combination of any of these to form a composite film. Nanocomposites are composite films made by incorporation of nanoparticles. Edible packaging and coating of the meat and meat products enhances the self-life by the incorporation of the active compound (such as antimicrobial and antioxidant compound) in to the packaging matrix. Incorporation of the some ingredients in the matrix may also improve the nutritional as well as sensory attributes of the

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packed products. Edible packaging material also reduces environmental pollution by overcoming the burden degradation as edible films are biodegradable and thus eco-friendly.

Keywords

Active packaging film, Antimicrobial, Biodegradable, Edible film, Meat and Meat products, Nano-composite films

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Introduction

Packaging has been defined as a socio-scientific discipline which operates in society to ensure delivery of goods to the ultimate consumer of those goods in the best condition intended for their use (Lockhart, 1997). Any packaging system should protect the contents from contamination and spoilage, promote the product i.e. makes product easier to transport and store and inform the consumer. Nowadays fourth function, convenience is gaining much interest among processors and consumer, which is closely related to promotion since convenient package promotes sales. In today's society, packaging is pervasive and essential. It's very first function begins from the point of containment, processing and manufacturing, protects and promote the product during handling, storage and sale and ultimately reaches retailers and consumers providing them the convenience of displaying, sale and purchase, cooking and consumption. But the darker side of packaging has come up as a major source of waste generation. US Environmental Protection Agency (EPA, 2006) had reported that packaging waste accounts for about 31% of the municipal solid waste (MSW). Total packaging waste by volume accounts for almost two-thirds of total waste generated in developed countries (Hunt et al., 1990). There is no precise data on the total amount of waste generated by the food industry in the EU-25. Food and drink processing on aggregate level would account for 12.5% of manufacturing industry's waste in these countries. In the EU as a whole, total manufacturing accounts for 26% of total waste generation. If the food industry's share of 12.5% was applied to this total EU data, food industry waste would account for about 3.25% of overall waste generation in the EU. Along with economic development in China, the quantity of solid waste generated has increased rapidly. The total quantity of MSW collected and transported in 2002 was 136.5 million tons. Thus,

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packaging technology must balance food protection with other issues, including energy and material costs, heightened social and environmental consciousness, and strict regulations on pollutants and disposal of municipal solid waste.

Edible films and coatings have received considerable attention in recent years because of their advantages including use as edible packaging materials over synthetic films. These films are generally biodegradable in nature making it an eco-friendly packaging approach. Thus, they contribute to the protection of the environment. This article explores the various aspects of its production and application in meat and meat products as an alternative to conventional packaging system.

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History of edible films

The use of edible films in food products seems new, but way back when these polymers were not developed, food products were packed in natural casings such as leaves, wood, baskets etc. First recorded use of biopolymer was in southern China around twelfth century where citrus fruits for the King were preserved by coating them with molten wax (Hardenhurg, 1967). In fifteenth century in Japan, Yuba, a proteic edible film was used to improve appearance and preservation of food (Biquet and Guilbert 1986; Gennadios, et al., 1993). This Yuba film is regarded as the first free standing film. Later in sixteenth century, in England larding i.e. coating with lard was practiced to prevent shrinkage (prolong shelf-life of meat) though this resulted in some loss of taste and texture (Contreras-Medellin and Lahuza, 1981). Use of gelatin to preserve meat was patented in US in nineteenth century (Havard and Harmony, 1869). During same period nuts, almonds and hazelnuts were coated with sucrose to prevent rancidity and enhance keeping quality. Later in 1930s emulsion of oil and waxes in water was applied on fruits to furnish shine, brightening appearance along with preventing moisture loss. This was sometimes also added with fungicides to prevent rotting.

Edible films processing

The formation of edible films can be done either by wet processing or dry processing. For wet processing films can be produced from materials with film forming ability. During manufacturing, film materials must be dispersed and dissolved in a solvent such as water, alcohol or mixture of water and alcohol or a mixture of other solvents. Plasticizers, antimicrobial agents, colors or flavors can be added in this process. Adjusting the pH and/or heating the solutions may be done for the specific polymer to facilitate dispersion. Film solution is then casted and dried at a desired temperature and relative humidity to obtain free standing films. Film solutions can be applied to food by several methods such as dipping, spraying, brushing and panning followed by drying.

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The dry process does not involves solvent dispersion as it relies on inherent thermoplastic characteristics of some biopolymers and are produced by compression, molding or extrusion (Pommet, et al., 2005; Liu, et al., 2006). The film formation and coating may involve anyone of the following processes:

- Melting and solidification of solid fats, waxes and resins
- Simple coacervation where a hydrocolloid dispersed in aqueous solution is precipitated or gelified by the removal of the solvent, by the addition of a non-electrolyte solute in which

the polymer is not soluble, by the addition of an electrolyte substance inducing a "salting out" effect, or by the modification of the pH of the solution

- Complex coacervation, where two hydrocolloid solutions with opposite charges are combined, inducing interactions and the precipitation of the polymer mixture
- Thermal gelation or coagulation by the heating of the macromolecule solution which involves denaturation, gelification, precipitation, or by a rapid cooling of the hydrocolloid solution that induces a sol-gel transition

Edible packaging material or films must have some functional and specific properties. Selective properties of edible films and coatings are summarized as

1. good water barrier efficiency
2. control of gas exchanges
3. retard solute transport
4. retard oil and fat migration
5. retard organic vapor transfers
6. improve mechanical properties of food to facilitate handling and carriage
7. Sensorial characteristics such as colour, shininess, transparency, roughness or sticking can be improved
8. Layers are not self-supporting

Components used for the preparation of edible films can be classified into three categories: hydrocolloids (such as proteins, polysaccharides, and alginate), lipids (such as fatty acids, acylglycerol, waxes) and composites. The formulation of films requires at least one component

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capable to form a structural matrix with a sufficient cohesiveness. Lipids or hydrophobic substances such as resins, waxes or some non-soluble proteins are the most efficient for the moisture transfer retardation. Water soluble hydrocolloids, like polysaccharides and proteins, are low efficient barrier against water transfer; however, their permeability to gases is often lower than those of plastic films. Hydrocolloids usually provide higher mechanical properties to edible packaging than lipids and hydrophobic substances. Natural film-forming substances, particularly proteins, need film additives such as plasticizers to improve film resistance and elasticity or such as emulsifiers to increase the hydrophobic globule distribution. Therefore, the advantages of all substances can be found in composite films.

Composite films are defined as films or coatings with heterogeneous structure, that is, composed of continuous matrix with some inclusions, such as lipidic globules in the case of an emulsion, or solid particles in the case of non-soluble substances (fibers, hydrophobic proteins), or is composed of several layers.

When films are used as carrier of food additives or ingredients, such as flavors, spices, antimicrobial, antioxidant agents, pigments, light absorbers, salts etc then such packaging is known as active packing. Functional efficiency of edible films strongly depends on the nature of components, film composition and structure. The choice of film-forming substance and/or active additive is a function of the objective, of the nature of the food product and of the application method. For successful application in meat products edible films must meet a range of functional requirements such as moisture-barrier ability, water or lipid solubility, colour, appearance, mechanical and rheological characteristics and non-toxicity (Guilbert et al., 1996).

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Protein based edible films with characteristic properties

Proteins inherently have interactive forces that provide cohesiveness which is essential for film formation. Protein films are generally formed by wet processing method where the solvents used may vary from water to ethanol or a combination of both (Kester and Fennema, 1986). For film formation it is necessary to have an open extended structure to stretch out, this is accomplished by denaturation of proteins. Denaturation of proteins can be furnished by heat, acid, base and /or solvent resulting into unfolding of the protein chains. Unfolded proteins interacts with each other and the solvent associates by variety of forces such as hydrogen bonding, hydrophobic, ionic of covalent bonding to give the film strength resulting in good mechanical and structural characteristics. Due to these bonding protein films exhibit excellent gas barrier but poor moisture barrier properties (Baldwin et al., 1995). Thus, protein films are expected to be good oxygen barriers at low relative humidity. This gas barrier property can be made use in preventing oxidative rancidity, enzymatic browning and minimizes flavor loss in meat and meat products (Olivas and Barbosa-Canovas, 2005). Lee and Krotcha, (2002) have shown to delay onset of rancidity in peanuts by applying whey protein edible coating. Caner, (2005) have showed that eggs coated with whey protein had a week longer shelf life than uncoated eggs. Protein films are brittle and susceptible to cracking due to the strong cohesive energy density of the polymer (Lim et al., 2002). Protein-based films have good organoleptic and mechanical properties, also acting as good barriers to non-condensable gases (O2, CO2 and N2) and aromas (Fabra et al., 2008). However, these films display high moisture adsorption, due to the hydrophilic nature of protein molecules (Prodpran et al., 2007). Various types of protein have

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been used as edible films. These include gelatin, casein, whey protein, corn zein, wheat gluten, soy protein, mung bean protein, and peanut protein (Bourtoom, 2008).

a) Collagen and Gelatin films

Collagen is the largest protein found in animal body. It is the principle structural protein constituting about 20-25 percent of total body proteins. A collagen molecule consists of triple helix of alpha chains. Collagen or its hydrolyzed form gelatin is widely used for production of edible films or coatings. Natural casings from sheep, goat and pigs have long been used for production of sausages. Collagen rich submucosal layer of intestine is used which provides sufficient flexibility and strength. These casings are one of the oldest used edible films. Collagen films have good mechanical properties but are fairly permeable to moisture at high relative humidity (Lieberman and Guilbert, 1973; Hood 1987). Collagen films have good tensile strength as hydrolysed collagen films at concentrations about 15 percent in film formation have tensile strength of about 100 MPa (Fadini et al., 2013). In the same study authors reported that on increasing the level of hydrolysed collagen the films had lower water vapour permeability and had finer homogenous structure (Fadini et al., 2013). Similarly gelatin films also have poor water barrier properties which can be attributed to its hydrophilic nature (Sobral et al., 2001; Prodpan et al., 2007).

b.) Myofibrillar proteins

Muscle proteins are generally classified into myofibrillar, sarcoplasmic and stromal proteins. Collagen is a stromal protein that has long been used as edible packaging material in sausage preparations. Recently myofibrillar and sarcoplasmic proteins obtained from fish were utilized for film production (Benjakul et al., 2008; Hamaguchi et al., 2007). The myofibrillar protein-

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myosin imparts good mechanical strength to the films. The sarcoplasmic proteins after denaturation, unfolds and forms continuous matrix for film formation. For this a thermal treatment of ≥50°C is required (Iwata et al., 2000). Muscle protein films can be made at acidic (2-3) as well as basic (7-12) pHs (Hamaguchi et al., 2007) but the protein concentration must be restricted to 3% while plasticizers like glycerol may be used from 15 to 65% (Sobral et al., 2005). Apart from fish muscle proteins edible films have also been developed from shrimp muscle proteins (Gomez-Estaca et al., 2014).

c.) Milk protein based films

In milk, protein content varies from 3.4 – 6.7 percent in various farm animals. Milk proteins consist of mainly casein, β-lactoglobulin, α-lactalbumin, serum albumin, proteose-peptone and immunoglobulins. Casein contributes the most to the protein content of milk constituting about 80 % of it. It is composed of α, β, γ fractions which can be observed by electrophoresis of which α-fraction can be further classified into α_s (Calcium sensitive) and κ-casein (Calcium insensitive). Later studies revealed that there are four different peptide chains — αs1, αs2, β, and κ, of which the molar ratio is about 11:3:10:4 (Walstra et al., 2005). The inherent property of molecular flexibility and randomly coiled polypeptides exhibiting various types of intermolecular bonding makes them a suitable raw material for film formation (Lacroix and Cooksey, 2005). Large numbers of polar groups provide excellent gas-barrier properties to casein based films but at the same time this hydrophilicity imparts inefficient moisture protection which is very much sorted for preventing shrinkage in meat and meat products (Audic et al., 2003).

The β-lactoglobulin and α-lactalbumin represents approximately 70% of the total whey proteins which are responsible for its gelling and thus film making properties (Cavot and Lorient,

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1997). Its conformational denaturation, the evenly distributed negative charge and amphiphilic nature imparts whey proteins a unique film forming ability. But a major drawback of such films is their low tensile strength.

d.) Egg White proteins:

Egg white protein films have similar properties like other protein based films. Egg albumin proteins are the main proteins responsible for film formation due to their abundant sulfhydryl and disulfide bonds. Other important constituents that participate in film formation are ovomucin fibres, conalbumin, ovomucoid, lysozyme and globulins. Jerez et al. (2007) have reported that egg white based films can be better processed at low temperatures which can be formed by moulding process.

e.) Corn Zein films

Zein, a prolamine protein characteristic of cereal proteins is the major storage protein of corn. It produces tough, glossy, grease-proof films with high tensile strength, low water vapour permeability coatings and heat sealability which are the most desirable characteristic of a packaging film (Cho et al., 2002; Park et al., 1996). These are produced by suspension of zein protein powder in ethyl alcohol and water followed by casting the solution on flat plates for drying. The tensile strength can be increased upto 74.2 MPa by increasing the ethanol solution or upto 57.5 MPa by using isopropanol solution (Chen et al., 2014). Cho et al., (2010) have showed that the seal strength of bilayer films of corn zein and soy protein isolates ranged from 25 to 345 N/m depending on the sealing temperature (85^o to 155^oC). Plasticizers are still required for improving flexibility. Addition of fatty acids may also enhance the water barrier properties.

f.) Wheat gluten films

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Edible films can be formed by drying aqueous ethanol or acetic acid solution of wheat gluten (Gennadios and Weller, 1990). Alkaline films can be formed suspending wheat gluten in ethanol/ ammonium hydroxide solution (Tanada-Palmu et al., 2000). The formation of film involves disulphide, hydrophobic and hydrogen bondings. Sulphhydryl groups are responsible for the disulphide bond formation. Heating causes opening of native disulphide and hydrophobic groups as well as denaturation of proteins. During drying, the dispersed gluten reoxidizes and forms new disulphide bonds. Plastisizers are still required to reduce brittleness in the films for which glycerol is widely used. Clarity of films depends on the purity of gluten and the medium used for casting i.e. acidic or alkaline. (Gennadios and Weller, 1992; Tanada-Palmu et al., 2000). The films formed are homogenous, mechanically strong, and may have selective gas barrier properties (Mojumdar et al., 2011). Gliadin and glutenin polypeptides with lipids and carbohydrates form the gluten and thus increasing the gliadin content improves the film properties. Chung-hong et al. (2010) have shown that a 3:1 ratio of wheat gluten and gliadin increases the tensile strength and water vapour barrier properties. When used as a coating on grade A-quality shell eggs, the egg quality were maintained for 30 days.

g.) Soy protein film

Soy protein isolates or soy protein milk is used for the production of soy protein based films. Soy proteins easily form films which are more flexible, smooth, transparent and cheaper than other protein films. Additionally they have an excellent oxygen barrier property under low relative humidity conditions which is much desired to prevent oxidation in meat products (Brandenburg et al., 1993). The major drawbacks of these films are lack of heat sealability, low mechanical strength and allerginicity as compared to low density polyethylene (LDPE). Aqueous

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solutions of soy protein isolate (SPI) can also form films on stainless steel plates at high temperatures.

h.) Other plant origin proteins

Legume proteins are a good source for production of edible films of which soy proteins have been long used. Nowadays with the advent of eco-friendly and biodegradable packaging scientists are exploring new protein sources. Pea proteins can be utilized to prepare edible films with similar water vapor permeability (WVP) and physical characteristics as that of whey or soy proteins (Choi and Han, 2001 and Choi and Han, 2002). Kowalczyk and Baraniak, (2011) reported that pea protein isolates can satisfactorily be utilized for packaging in food industries. Sun et al., (2013) elucidated that combining 40% of pea protein isolates into pea starch yielded films with desirable properties.

Studies of Chang and Nickerson, (2013) revealed that canola protein isolate can also be utilized for edible film formation. Such films were less brittle, more malleable and transparent, and had greater water vapor permeability at higher glycerol levels. Films made from pumpkin oil cake have good gas barrier properties, tensile strength and has elongation ability similar or even higher than cellophane (Popovic et al., 2011). Zahedi et al., (2010) prepared novel edible composite films using the emulsification technique from pistachio globulin protein (PGP), saturated fatty acids, and an emulsifier (Tween 80).

One of the biggest hurdles in commercial application of protein films in meat and meat products is the health risks like allergies related to milk, egg, soybean etc.

Polysaccharide based films with characteristic properties

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Polysaccharides are hydrocolloids of high molecular weight which in water form intensive hydrogen bonds to form gel. Linear and neutral types of polysaccharides like agar, curdlan, methylcellulose, hydroxypropyl methylcellulose (HPMC), gellan, and cereal β -glucan form best films (Nieto, 2009). Polysaccharides based edible films have excellent mechanical and structural properties. These are generally very hydrophilic and impart compactness, viscosity and gel forming ability to the films. When applied to wrapped meat products and subjected to smoking and steam, the polysaccharide films actually dissolves and becomes integrated into the meat surface. Improvements in structure, texture and higher yields due to reduced moisture loss have been observed in polysaccharide treated meats (Cutter, 2006).

a) Cellulose and derivatives

Cellulose is the most abundant biopolymer on earth. Chemical modification of the naturally present cellulose yields various forms of cellulose such as carboxymethyl cellulose (CMC), methyl cellulose (MC), hydroxypropyl methyl cellulose (HPMC) or hydroxypropyl cellulose (HPC). All these forms have some unique characteristics depending on the chemical treatment given. These derivatives also have an excellent film forming properties owing to its structural conformity. These form films which are generally colourless, odourless, tasteless and flexible with moderate strength, water vapour and oxygen permeabilities (Krochta and De-Mulder-Johnson, 1997). Cellulose films have lower oxygen permeability than low density polyethylene (Park and Chinnan, 1995). Methyl cellulose has lowest hydrophilic content among cellulose derivatives and thus it is the most water resistant. It also forms stronger films than HPMC (Nieto, 2009). Maskat et al., (2005) have shown that application of 2.5% methyl cellulose coating improved the cooking yield and reduced coating and frying losses in fried coated chicken

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breasts. Regenerated cellulose casings are widely used for sausage preparations (Sreenath and Jeffries, 2011).

b) Chitin and Chitosan

Chitin is the second most abundant naturally occurring biopolymer and is found in the exoskeleton of crustaceans, mollusks, some arthropods and fungi (Andrady and Xu, 1997; Suyatma et al., 2004). Chitosan is derived from chitin by deacetylation and commercially available chitosan is 85% deacetylated. Chitosan has many desirable physicochemical properties such as biodegradability, biocompatibility with human tissues, non-toxic and possess antimicrobial and antifungal properties (Aider, 2010). Chitosan forms strong films. Aqueous chitosan forms strong, elastic and clear films with good oxygen barrier properties (Kalplan et al., 1993) while methylation may also improve its carbon dioxide permeability. One of its desirable characteristic is its antioxidant property which can be attributed to its ability to chelate free iron (Kamil et al., 2002). Suman et al. (2010) showed that coating ground beef patties with chitosan reduced TBARS values and improved the surface red colour of patties as compared to non-coated samples.

c) Starch

Starch because of its abundance, low cost, renewability, good mechanical properties, biodegradable and thermoplastic nature is an important source for edible films production (Mali et al., 2005; Xu et al., 2005). Flores et al. (2007) have reported that tapioca starch based edible films are isotropic, colourless, odourless and harmless but pure tapioca starch films are very brittle and thus addition of plasticizers is essential to improve the flexibility (Lu et al., 2009).

d) Pectin derivatives

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Pectin is a heteropolysaccharide obtained from fruits and vegetables. Commercially they are obtained from citrus peels and apple juices waste. It consists of β-1, 4-linked D-galacturonic acid residues and different levels of methyl esterification of the carboxyl groups of uronic acid produces various chemical forms of pectin (Marudova et al., 2004). Pectin forms homogenous and clear films (Galus and Lenart, 2013) but such films have poor moisture barrier property.

e) Seaweed extracts

Agar is a fibrous carbohydrate obtained from marine algae of the class Rhodophyceae (called 'red seaweeds') such as *Gelidium* and *Gracilaria spp*. which can be used for preparation of ecofriendly films (Rhim, 2011). Wu et al. (2009) reported that the addition of agar to starch improved the barrier properties of the film.

Alginates are structural polysaccharides extracted from *Phaeophyceae* seaweeds (brown algae) like *Macrocystis, Laminaria and Ascophyllum*. Alginate films are resistant to oil and grease. Di- and tri-valent ions like calcium, magnesium, aluminium, etc are generally added to enhance the gelling capacity of the solution for film formation as they assist in inter-chain hydrogen bonds. The ability of alginates to combine with divalent ions is utilized for film formation

Rhodophycae members like *Eucheuma*, *Gigartina* and *Chondrus spp*. are generally used for harvesting carrageenan commercially. kappa I, kappa II, iota and lambda are the various types of chemical forms of carrageenan. These films also have poor water barrier properties.

f) Microbial fermentation gums

Some microbial polysaccharides are also being used for commercial production of biopolymers such as Xanthan gum from *Xanthomonas campestris* and gellan gum from

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Sphingomonas spp. Bacterial alginates from are *Pseudomonas sp*. and *Azotobacter spp. and* bacterial cellulose from *Acetobacter xylinium* have also been studied.

Lipid based Films with characteristic properties

Lipids are hydrophobic substances which have excellent moisture barrier property and thus these were the very first kind of coating used on fresh meats as 'Larding'. Lard in sixteenth century was applied on meat surfaces to prevent shrinkage. Later commercially beewax, paraffin, mineral and vegetable oils were also used (McGrath, 1955). The barrier property of pure lipid films is a function of its thickness. But lipid films are brittle, with poor strength and elasticity. Thus, lipids better form composite films with hydrocolloids or proteins rather than alone (Debeaufort et al., 1993).

a.) Waxes and paraffin

The various waxes used are paraffin wax, bee wax, carnauba wax, candelilla wax. Paraffin is the product of fractional distillation of crude petroleum while bee wax is produced by the honey bees. Carnauba wax is exudates collected from palm tree leaves and Candelilla wax is obtained from candelilla plant. Mineral oils and vegetable oils are also in vogue.

b.) Acetoglycerides

These are acetylated products of glycerides and triacetin or acetic anhydride formed by interesterification. Lovegren and Feuge, (1954) reported that acetolycerides forms a flexible wax-like coating after solidifying. Actogycerides have moderate to good elasticity and water vapour barrier properties (Kester and Fennema, 1986).

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Composite edible films with characteristic properties

Edible films from the above mentioned sources have some or the other drawbacks for which they do not satisfy the requirements of an ideal packaging film. Thus a better way out of it is the combination of various films to produce one film with the desired properties specifically for the product to be packed. For packaging fresh meat the film should have low water vapour permeability but good oxygen permeability. It should not impart any odour or hamper visibility and exhibit no migration characteristics. While cooked and/or cured meat products essentially require absolute oxygen barrier. Cured meats easily get faded in light so they must be packaged in opaque films. Proteins and polysaccharides form excellent matrix for film formation with good mechanical strength but its high water vapour transmission property limits its application. If the protein or polysaccharide matrix is coated with lipids then a film with good strength and barrier properties can be produced (Garcia et al., 2000). This concept of composite films is in vogue in development of eco-friendly and biodegradable packaging biopolymers.

Composite films can be formed by extruding blends of polysaccharides, proteins and/or lipids; by laminating two or more edible films or by emulsion formation (Liu et al., 2005; Kurek et al., 2014; Perez-Gago and Krotcha, 2001). The main objective of composite films is to improve the permeability or mechanical properties according to the specific application. The method of application affects the barrier properties of the films obtained. The functional properties of a composite film not only depend on the individual film characteristics but also on the interaction among the constituents (de Souza, et al., 2010). Lamination of whey proteins and chitosan polymer is a valuable method to produce film with desired functional properties (Kurek

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et al., 2014). Sodium alginate and pectin form continuous, homogenous and transparent composite films with good tensile strength and moderate water vapour permeability (Galus and Lenart, 2013). Similarly various combinations have been studied such as corn zein and corn starch (Ryu et al., 2002), gelatin and fatty acid (Bertan et al., 2005), soy protein isolate and gelatin (Cao et al., 2002), soy protein isolate and poly-lactic acid (Rhim et al., 2007). Composite of whey proteins and acetylated mono-glycerides prevented lipid oxidation and water loss of salmon (Stuchell and Krochta, 1995).

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Nano-composite technology

Nanocomposites (NCPs) are novel polymers formed by extruding blends of polysaccharides, proteins and/or lipids or by laminating two or more edible films or by emulsion formation, which have essentially been incorporated with nanoparticles. The microstructure of composites consists of a continuous phase and a discontinuous phase or filler (Matthews and Rawlings, 1994). The continuous phase or matrix is formed by the polymer while the discontinuous phase or filler may be the active components like antioxidants or antimicrobials or metals or ions. In nano-composites the filler material/nano-components or materials have at least one dimension smaller than 100 nm (Neethirajan and Jayas, 2011). The antimicrobial effect of nanoparticles is due to its interference with vital cellular processes of the microorganisms, disruption of replication and by induction of oxidative stress on target agents. These particles hinder the binding sites on the membranes and retards enzymatic activities. The incorporation of antioxidants in the composite films is done either by encapsulation or by reducing the size of active ingredients in the nano scale range such as shelf assembled nano-structures.

Nanotechnology has been used to generate new products with desirable characteristics such as enhanced shelf-life, delayed spoilage and protection from food-borne pathogens (Duncan, 2011; Ozcalik and Tihminlioglu, 2013).

These composites have quite different mechanical and thermal properties than their component materials. Starch-clay has been widely studied nano-composites suitable for incorporation in food packaging industry (Avella et al., 2005; Yoon and Deng 2006; Cyras et al., 2008). Cabedo et al., (2006) reported that amorphous polylactic acid (PLA) and kaolinite (clay) effectively decreased the oxygen permeability of the nanocomposite formed. TiO2 nanoparticles incorporated in whey protein films imparted improved antimicrobial property to the whey protein films (Sothornvit and Krochta, 2005). Thus, TiO2 nanocomposites incorporated whey protein films can be used as ecofriendly food grade films (Zhou et al., 2009). Similarly ZnO–whey protein non-composites have also been studied (Shi et al., 2008).

Active edible films

Active packaging refers to the incorporation of certain additives into packaging film or within packaging containers with the aim of maintaining and extending product shelf-life (Day, 2003). It enhances shelf, stability and improve qualities both microbial and sensorial (Khalil et al., 2013). Antioxidants and antimicrobials are the most commonly used active components in packaging films to prevent spoilage, enhance safety and consumer confidence. Active packaging incorporated with antimicrobials can overcome the hurdles of uncontrolled migration and interaction of active compounds of various natural antioxidants used directly on food (Kuswandi et al., 2011; Morsy et al., 2014). Active packaging is an innovative concept in the field of food

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science which can benefit fresh foods with extended shelf-life (Marcos et al., 2013). It has been shown that application of hydrocolloids along with organic acids such as lactic or acetic acids reduce microbial growths (*Listeria monocytogenes*) on meat pieces.

Camo et al., (2008) observed enhanced oxidative stability of lamb steaks placed in rosemary active film and oregano active film. Cold-smoked sardine coated with gelatin films containing essential oils showed decreased malonaldehyde content during storage at 5^{o} C (Gómez-Estaca et al., 2007). In other study, Ojagh et al. (2010) reported an increase in shelf-life of trout fillets coated with chitosan film enriched with cinnamon.

Several antimicrobial compounds such as organic acids, enzymes such as lysozyme, fungicides such as benomyl, imazalil, essential oils and spices can be effectively used in films against food-borne pathogens such as *E. coli*, *Campylobacter jejuni*, *Salmonella enterica*, and *L. monocytogenes* (Olasupo et al., 2003). Rosemary and oregano essential oils, and silver and zinc oxide nanoparticles incorporated into pullulan films were effective against pathogenic microorganisms, such as *S. aureus*, *L. monocytogenes*, *E. coli O157:H7*, and *S. Typhimurium* (Morsy et al., 2014). Natural compounds, such as nisin and lysozyme, have also been studied as potential food preservatives which can be added to edible films (Cagri, et al., 2004). Bacteriocins such as nisin and divergicin have also been studied for their antimicrobial properties in chitosan based films (Tahiri et al., 2004; Tahiri, et al., 2009). Oregano and garlic essential oil added films were effective against *S. aureus, S. enteritidis, L. monocytogenes, E. coli* and *L. plantarum* (Seydim and Saricus, 2006).

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Conclusion

Edible film application on meat and meat products requires some important considerations. These must meet standards issued by the National authorities. According to the European Directive and USA regulations, edible films and coatings can be classified as food products, food ingredients, food additives, food contact substances, or food packaging materials (ED European Parliament and Council Directive No95/2EC; FDA 2006). FDA has issued GRAS label for some edible films which can be used on foods intended for human consumption. The application of nanotechnology and the effectiveness of added antimicrobials and anti-oxidants have opened a new field of research for the development of edible films on preservation of meat and meat products. Sustainable application and use of edible films requires a synergistic effort of both the polymer and food technologists to develop packaging materials which can overcome the drawbacks of a natural film. Next-generation packaging materials need to be biodegradable, sustainable and natural along with strength and plasticity of synthetic polymers.

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References

Aider, M. (2010). Chitosan application for active bio-based films production and potential in the food industry: Review. *LWT - Food Sci Technol*. **43**: 837–842.

Anderson, T.R. (1960). Manner of handling meat. U.S. Patent 2,948,623, August 9.

Andrady, A. L. and Xu, P. (1997). Elastic behavior of chitosan films. *J Polym Sci*. **5**: 307- 521.

Audic, J.L., Chaufer, B. and Daufin, G. (2003). Non-food applications of milk components and dairy co-products: A review. *Le Lait Dairy Sci Technol*. **83**(6): 417 – 438.

Avella, M., De Vlieger, J.J., Errico, M.E., Fischer, S., Vacca, P. and Volpe, M.G. (2005). Biodegradable starch/clay nanocomposite films for food packaging applications. *Food Chem*. **93**: 467–74.

Baldwin, E.A., and Nisperos-Carriedo, M.O., Eds., Technomic Publishing Co. Inc., Basel.

Balasubramanium, V.M., Chinnan, M. S., Mallikajunan, P. and Phillips, R. D. (1997). The effect of edible film on oil uptake and moisture retention of a deep-fried poultry product. *J Food Process Eng*. **20**: 17-29.

Benjakul, S., Artharn, A., and Prodpran, T. (2008). Properties of protein-based film from round scad (Decapterus maruadsi) muscle as influenced by fish quality. *LWT - Food Sci Technol*. **41**(5): 753-763.

Bertan, L.C., Tanada-Palmu, P.S., Siani, A.C. and Grosso C.R.F. (2005). Effect of fatty acids and ‘Brazilian elemi’ on composite films based on gelatin. *Food Hydrocolloid*. **19**(1): 73–82.

Downloaded by [New York University] at 14:09 23 June 2015

Downloaded by [New York University] at 14:09 23 June 2015

Biquet, B. and Guilbert, S. (1986). Relative diffusivitives of water in model intermediate moisture foods. *LWT- Food Sci. Technol*. **19**: 208 – 214.

Bourtoom, T. (2008). Edible films and coatings: characteristics and properties. *Inter Food Res J (IFRJ)*. **15** :(3). ISSN 1985-4668.

Brandenburg, A.H., Weller, C.L. and Testin, R.F. (1993). Edible films and coatings from soy protein. *J Food Sci*. **58**(5):1086–89.

Cabedo, L., Feijoo, J.L., Villanueva, M.P., Lagaron, J.M. and Gimenez, E. (2006). Optimization of Biodegradable nanocomposites based on a PLA/PCL blends for food packaging applications. *Macromol Symp*. **233**(1):191–7.

Cagri, A., Ustunol, Z., and Ryser, E. T. (2004). Antimicrobial edible films and coatings. *J Food Protec*. **67**(4): 833-848.

Camo, J., Beltrán, J.A. and Roncalés, P. (2008). Extension of the display life of lamb with an antioxidant active packaging. *Meat Sci*. **80**: 1086–1091.

Caner, C., (2005). Whey protein isolates coating and concentration effects on egg shelf life. *J. Sci. Food Agric*. **85**: 2143-2148.

Cao, N., Fua, Y. and He, Y. (2002). Preparation and physical properties of soy protein isolate and gelatin composite films. *LWT-Food Sci Technol*. **35**: 680–686.

Caprioli, I., O'Sullivan, M. and Monahan F. J. (2009). Use of sodium caseinate/glycerol edible films to reduce lipid oxidation in sliced turkey meat. Eur Food Res and Technol. **228**(3): 433-440.

Cavot and Lorient, (1997): Chp 8 Structure function Relationships of whey proteins. pp 225. **In** Food Proteins and their application. Damodaran and Paraf, Eds. Marcel Dekker, Inc., New York.

Chang, C. and Nickerson, M.T. (2013). Effect of protein and glycerol concentration on the mechanical, optical, and water vapor barrier properties of canola protein isolate-based edible films. *Food Sci Technol Int*. **70**: 124. 1082013213503645

Chen, Y., Ye, R. and Liu, J. (2014). Effects of different concentrations of ethanol and isopropanol on physicochemical properties of zein-based films. *Ind Crop Prod*. **53**:140– 147.

Chidanandaiah, Keshri, R.C. and Sanyal, M.K. (2009). Effect of sodium alginate with preservatives on the quality of meat patties during refrigerated (4±1^{o}C) storage. *J Muscle Food*. **20**: 275-292.

Cho, S. Y., Lee, S. Y. and Rhee C. (2010). Edible oxygen barrier bilayer film pouches from corn zein and soy protein isolate for olive oil packaging. *LWT - Food Sci Technol*. **43**(8): 1234–1239.

Cho, S.Y., Park, J.W. and Rhee, C. (2002). Properties of laminated films from whey powder and sodium caseinate mixtures and zein layers. *LWT - Food Sci Technol*. **35**(2):135-139.

Choi, W.S. and Han, J.H. (2001). Physical and mechanical properties of pea–protein-based edible films. *J. Food Sci*. **66**: 319–322.

Downloaded by [New York University] at 14:09 23 June 2015

Choi, W.S. and Han, J.H. (2002). Film-forming mechanism and heat denaturation effects on the physical and chemical properties of pea-protein-isolate edible films. *J. Food Sci.* **67**: 1399–1406.

Contreras-Medellin, R. and Labuza, T.P. (1981) Prediction of moisture protection requirements for foods. *Cereal Food World*. **26**(7): 335-340.

Corrales, M., Han, H J. and Tauscher, B. (2009). Antioxadant and antimicrobial properties of grape seed extracts and their application into pea starch films for meat preservation. *Int J Food Sci Tech*. **44**: 425-433.

Cutter, C.N. (2006). Opportunities for bio-based packaging technologies to improve the quality and safety of fresh and further processed muscle foods. *Meat Sci*. **74**(1): 131-142.

Cutter, C.N. and Sumner, S.S. (2002). Application of edible coatings on muscle foods. **In**: Protein-based films and coatings, pp. 467–484. Gennadios, A., Ed., CRC Press, Boca Raton, FL.

Cyras, V.P., Manfredi, L.B., Ton-That, Minh-Tan, Vázquez, A. (2008). Physical and mechanical properties of thermoplastic starch/montmorillonite nanocomposite films. *Carbohyd Polym.* **73**(1): 55–63.

Day, B.P.I. (2003). Chp 9 Active packaging. **In**: Food Packaging Technology, Coles, R., McDowell, D., and Kirwan, M., Eds. CRC Press, Boca Raton, FL.

Debeaufort, F., Martin-Polo, M. and Voilley, A. (1993). Polarity homogeneity and structure affect water vapor permeability of model edible films. *J Food Sci*. **58**: 426-434.

Downloaded by [New York University] at 14:09 23 June 2015

De-Souza, P. M., Fernández, A., López-Carballo, G., Gavara, R. and Hernández-Muñoz, P. (2010). Modified sodium caseinate films as releasing carriers of lysozyme. *Food Hydrocolloid* **24**(4): 300–306.

Duan, J., Cherian, G., Zhao, Y., (2010). Quality enhancement in fresh and frozen lingcod (Ophiodon elongates) fillets by employment of fish oil incorporated chitosan coatings. *Food Chem*. **119**: 524–532.

Duncan, T.V. (2011). Applications of nanotechnology in food packaging and food safety: barrier materials, antimicrobials and sensors. *J Colloid Interface Sci*. **36**:1–24.

EPA. 2006. Municipal solid waste in the United States: 2005 facts and figures. EPA530-R-06-011.

Fabra, M. J., Talens, P. and Chiralt, A. (2008). Tensile properties and water vapor permeability of sodium caseinate films containing oleic acid–beeswax mixtures. *J Food Eng*. **85**(3): 393–400.

Fadini, A.L., Rocha, F.S., Alvim, I.D., Sadahira, M.S., Queiroz, M.B., Alves, R.M.V. and Silva, L.B. (2013). Mechanical properties and water vapour permeability of hydrolysed collagenecocoa butter edible films plasticised with sucrose. *Food Hydrocolloid*. **30**: 625-631.

Flores, S., Famá, L., Rojas, A.M., Goyanes, S., and. Gerschenson, L. (2007). Physical properties of tapioca-starch edible films: Influence of filmmaking and potassium sorbate. *Food Res Int*. **40**: 257–265.

Downloaded by [New York University] at 14:09 23 June 2015

Gadang, V.P., Hettiarachchy, N. S., Johnson, M. G., and Owens, C. (2008). Evaluation of antibacterial activity of whey protein isolate coating incorporated with nisin, grape seed extract, malic acid, and EDTA on a turkey frankfurter system. *J Food Sci*. **73**(8): 389-394.

Galus, S. and Lenart, A. (2013). Development and characterization of composite edible films based on sodium alginate and pectin. *J Food Eng*. **115**(4): 459–465 2nd ISEKI_Food conference.

Garcia, M.A., Martino, M.N. and Zaritzky, N.E. (2000). Lipid addition to improve barrier properties of edible starch-based films and coatings. *J Food Sci*. **65**: 941–947.

Gennadios, A. and Weller, C.L. (1990). Edible films and coatings from wheat and corn proteins. *Food Technol*. **44**(10): 63–69.

Gennadios, A. and Weller, C.L. (1992) Tensile strength increase of wheat gluten films. Paper No. 92-6517. Presented at the International Winter Meeting of the American Society of Agricultural Engineers, Nashville, TN, December 15–18.

Gennadios, A., Weller, C.L., and Testin, R.F. (1993). Property modification of edible wheat, gluten-based films. *Trans Am Soc Agric Eng*. **36**(2): 465.

Gimenez, B., Gómez-Guillén, M.C, Pérez-Mateos, M., Montero, P. and Márquez-Ruiz, G. (2011). Evaluation of lipid oxidation in horse mackerel patties covered with borage-containing film during frozen storage. *Food Chem*. **124**: 1393–1403.

Gomez-Estaca, J., Montero, P. and Gómez-Guillén, M.C. (2014). Shrimp (*Litopenaeus vannamei*) muscle proteins as source to develop edible films. *Food Hydrocolloid*. **41**: 86-94.

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Gómez-Estaca, J., Montero, P., Giménez, B., Gómez-Guillén, M.C. (2007). Effect of functional edible films and high pressure processing on microbial and oxidative spoilage in cold-smoked sardine (Sardina pilchardus). *Food Chem*. **105**: 511– 520.

Gontard, N., Thibault, R., Cuq, B. and Guilbert, S. (1996). Influence of relative humidity and film composition on oxygen and carbon dioxide permeabilities of edible films. *J Agr Food Chem*. **44**: 1064–1069.

Guo, M. Jin, T.Z. Wang, L. Scullen, O.J. and Sommers, C.H. (2014). Antimicrobial films and coatings for inactivation of Listeria innocua on ready-to-eat deli turkeymeat. *Food Control*, **40**: 64-70.

Guilbert, S. Gontard, N. and Gorris, L.G.M. (1996). Prolongation of the shelf-life of perishable food products using biodegradable films and coatings. *Lebensmittel Wissenschaft und Technolo*. **29**: 10–17

Hamaguchi, P.Y., WuYin, W. and Tanaka, M. (2007). Effect of pH on the formation of edible films made from the muscle proteins of blue marlin (Makaira mazara). *Food Chem*. **100**(3): 914-920.

Hardenburg, R.E. (1967). Wax related coatings for horticultural products. A bibliography. Agricultural Research Service Bulletin 51-15, United States Department of Agriculture, Washington, DC.

Havard, C. and Harmony, M.X. (1869) Improved process for preserving meat, fowls, fish etc. U.S. Patent 90, 944

Higueras, L., L´opez-Carballo, G., Hern´andez-Mu˜noz, P., Gavara, R.and Rollini, M. (2013) Development of a novel antimicrobial filmbased on chitosan with LAE (ethyl-Nα-dodecanoyl-L-arginate) and its application to fresh chicken. *Int J Food Micro*. **165**(3): 339–345.

Hood, L. L. (1987). Advances in Meat Research, Van Nostrand Reinhold, New York, NY, pp. 109-129.

Hunt, R.G., Sellers, V.R., Frankalin, W.E., Nelson, J.M., Rathje, W.L., Hughes, W.W. and Wilson, D.C. (1990). Estimates of the volume of MSW and selected components in trash cans and land fills. Tucson, Ariz. Report prepared by The Garbage Project and Franklins Assn. Ltd. for the Council for Solid Waste Solutions.

Iwata, K., Ishizaki, S., Handa, A., and Tanaka, M. (2000). Preparation and characterization of edible films from fish water-soluble proteins. *Fisheries Sci*. **66**(2): 372-378.

Jeon, Y.I., Kamil, J.Y.V.A. and Shahidi, F. (2002). Chitosan as an edible invisible film for quality preservation of herring and Atlantic cod. *J Agr Food Chem*. **20**: 5167–5178.

Jerez, A., Partal, P., Martínez I., Gallegos C. and Guerrero, A. (2007). Egg white-based bioplastics developed by thermomechanical processing. *J Food Eng*. **82**(4): 608–617.

Kamil, J., Jeon, Y.J. and Shahidi, F. (2002). Antioxidant activity of chitosans of different viscosity in cooked comminuted flesh of herring (Clupea harengus). *Food Chem*. **79**: 69–77.

Kang, H.J., Jo, C., Kwon, J.H., Kim, J.H., Chung, H.J. and Byun, M.W. (2007). Effect of a pectin-based edible coating containing green tea powder on the quality of irradiated pork patty. *Food Control*. **18**(5): 430–435.

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 ACCEPTED MANUSCRIPT

Kaplan, D. L., Mayer, J. M., Ball, D., McCassie, J., Allen, A. L. and Stenhouse, P. (1993). Fundamental of biodegradable polymer. **In**: Biodegradable Polymers and Packaging, pp. 1-42 Ching, C., Kaplan D., and Thomas E. Eds.,. Lancaster: Technomic Publishing.

Kester, J. J. and Fennema, O. R. (1986). Edible films and coatings: A review. *Food Technol*. **40**(12): 47-59.

Khalil, M. S., Ahmed, Z. S. and Elnawawy, A. S. (2013). Evaluation of the physicochemical properties and antimicrobial activities of bioactive biodegradable films. *Jordan J Biol Sci*. **6**:51-60.

Kowalczyk, D. and Baraniak, B. (2011). Effects of plasticizers, pH and heating of film-forming solution on the properties of pea protein isolate films. *J Food Eng*. **105**: 295–305.

Krochta, J.M. and De-Mulder-Johnson, C. (1997). Edible and biodegradable polymer films: Challenges and opportunities. *Food Technol*. **51**(2): 61–77.

Kroger, M. and Igoe, R. S. (1971). Edible containers. Food Product Development, **5**(11): 74-76.

Kurek, M., Galus, S. and Debeaufort, F. (2014). Surface, mechanical and barrier properties of bio-based composite films based on chitosan and whey protein. *Food packag shelflife*. **1**: 56-67.

Kuswandi, B., Wicaksono, Y., Abdullah, A., Yook Heng, L. and Ahmad, M. (2011). Smart packaging: sensors for monitoring of food quality and safety. *Sens Instrum Food Qual*. **5**:137-46.

Downloaded by [New York University] at 14:09 23 June 2015

ACCEPTED MANUSCRIPT

Lacroix, M. and Cooksey, K. (2005). Edible films and coatings from animal-origin proteins. **In**: Innovations in food packaging, pp 301-17, Han, J.H., Ed. Elsevier Academic Press, San Diego, California

Lee, S.Y. and Krochta, J.M., (2002). Accelerated shelf life testing of whey-protein-coated peanuts analyzed by static headspace gas chromatography. *J Agr Food Chem*. **50**: 2022–2028.

Letney, L. R. (1958). Method of coating freshly cut surfaces of meat. U.S. Patent 2,819,975, January 24.

Lieberman, E. R. and Guilbert, S. G. (1973). *Polym Sci Symp*. **41**: 33-43.

Lim, L.T., Mine, Y., Britt, I.J. and Tung, M.A. (2002). Protein-Based Films and Coatings, CRC Press, Boca Raton, FL, pp. 233-252.

Liu, L., Kerry, J. F., and Kerry, J. P. (2005). Selection of optimum extrusion technology parameters in the manufacture of edible/biodegradable packaging films derived from food-based polymers. *J Food Agr Environ*. **3**: 51-58.

Liu, L., Kerry, J.F. and Kerry, J. P. (2006). Effect of food ingredients and selected lipids on the physical properties of extruded edible films/casings. *Int J Food Sci Tech*. **41**:295–302.

Lockhart, H. E. (1997). A Paradigm for Packaging. **In**: Packaging Technology and Science. **10**(5): 237–252.

Lovegren, N. V. and Feuge, R.O. (1954). Permeability of acetostearin products to water vapour. *J Agr Food Chem*. **2**: 558- 563.

Downloaded by [New York University] at 14:09 23 June 2015

 ACCEPTED MANUSCRIPT

Lu, D.R., Xiao, C.M., and Xu, S.J. (2009). Starch-based completely biodegradable polymer materials. Journal of Polymer Science Part C: Polymer Letters, 3, 366–375.

Mali, S., Grossmann, M. E., García, M. A., Martino, M. N., and Zaritzky, N. E. (2005). Mechanical andthermalproperties of yamstarchfilms. *Food Hydrocolloid*. **19**(1): 157–164.

Marcos, B, Aymerich, T, Garriga, M and Arnau, J. (2013). Active packaging containing nisin and high pressure processing as post-processing listericidal treatments for convenience fermented sausages. *Food Control*. **30**:325–30.

Marudova, M., MacDougall A.J. and Ring S.G. (2004). Pectin–chitosan interactions and gel formation. *Carbohydrate Res*., 339: 1933-1939.

Maskat, M. Y., Yip, H. H. and Mahali, H. M. (2005). The performance of a methyl cellulose-treated coating during the frying of a poultry product. *Int J Food Sci Tech*. **40**(8): 811–816.

Matthews, F. L. and Rawlings, R. D. (1994). Composite materials: engineering and science, pp. 137, London: Chapman and Hall.

McGrath, E.P. (1955). Packaging costs cut quality protected by wax coating frozen meats. *Food Eng*. **27**(8): 50-77.

Meyer, R, Winter, A. and Weister, H. (1959). Edible Protective Coatings for Extending the Shelf Life of Poultry. *Food Technol*. **13**:146-148.

Downloaded by [New York University] at 14:09 23 June 2015

Morsy, M. K., Khalaf, H. H., Sharoba, A. M., El-Tanahi, H. H., and Cutter C. N. (2014). Incorporation of Essential Oils and Nanoparticles in Pullulan Films to Control Foodborne Pathogens on Meat and Poultry Products. *J Food Sci*. **79**(4): 675-684.

Neethirajan, S. and Jayas D.S. (2011). Nanotechnology for the food and bioprocessing industries. *Food Bioprocess Technol*. **4**: 39–47.

Nieto, M.B. (2009). Chp 3 Structure and Function of Polysaccharide Gum-Based Edible Films and Coatings. **In**: Edible Films and Coatings for Food Applications, pp 59 & 65, Milda E. Embuscado, Kerry C. Huber, Eds. Springer Dordrecht Heidelberg London New York..

Ojagh, S.M., Rezaei, M., Razavi, S.H. and Hosseini, S.M.H. (2010). Development and evaluation of a novel biodegradable film made from chitosan and cinnamon essential oil with low affinity toward water. *Food Chem*. **122**: 161–166

Olasupo, N. A., Fitzgerald, D.J., Gasson, M.J. and Narbad, A. (2003). Activity of natural antimicrobial compounds against Escherichia coli and Salmonella enterica serovar Typhimurium. *Lett Appl Microbiol*. **37**:448–51.

Olivasa, G. I. and Barbosa-Cánovas, G. V. (2005). Edible Coatings for Fresh-Cut Fruits. *Crit Rev Food Sci Nutr*. **45**(7-8): 657-670.

Ou, S., Wang, Y., Tang, S., Huang, C. and Jackson, M., (2005). Role of ferulic acid in preparing edible films from soy protein isolate. *J Food Eng*. **70**: 205–210.

Downloaded by [New York University] at 14:09 23 June 2015

Oussalah, M., Caillet, S., Salmiéri, S., Saucier, L. and Lacroix, M., (2004). Antimicrobial and antioxidant effects of milk protein-based film containing essential oils for the preservation of whole beef muscle. *J Agr Food Chem*. **52**: 5598–5605.

Ozcalik, O. and Tihminlioglu, F. (2013). Barrier properties of corn zein nanocomposite coated polypropylene films for food packaging applications. *J Food Eng*. **114**:505–13.

Park, H. J. and Chinnan, M. S. (1995). Gas and water vapor barrier properties of edible films from protein and cellulosic materials. *J Food Eng*. **25**: 497–507.

Park, J.W., Testin R.F., Vergano, P.J., Park, H.J. and Weller, C.L. (1996). Application of laminated edible films to potato chip packaging. *J Food Sci*. **61**(4): 766-768.

Perez-Gago, M. B., and Krochta, J. M. (2001). Lipid particle size effect on water vapor permeability and mechanical properties of whey protein beeswax emulsion films. *J Agr Food Chem*. **49**(2): 996-1002.

Pommet, M., Redl, A., Guilbert, S. and Morel, M. (2005). Intrinsic influence of various plasticizers on functional properties and reactivity of wheat gluten thermoplastic materials. *J Cereal Sci*. **42**: 81–91.

Popovic, S., Pericin, D., Vastag, Z., Popovic, L. and Lazic, V. (2011). Evaluation of edible film-forming ability of pumpkin oil cake; effect of pH and temperature. *Food Hydrocolloid*. **25**: 470-476.

Downloaded by [New York University] at 14:09 23 June 2015

ACCEPTED MANUSCRIPT

Prodpran, T., Benjakul, S., and Artharn, A. (2007). Properties and microstructure of protein-based film from roundscad (Decapterus maruadsi) muscle as affected by palm oil and chitosan incorporation. *Int J Biol Macromol*. **41**: 605–614.

Rhim, J. W., Lee, J. H. and Ng, P. K. W. (2007). Mechanical and barrier properties of biodegradable -based films coated with polylactic acid. *LWT - Food Sci Technol*. **40**: 232-238.

Rhim, J.W. (2011). Effect of clay contents on mechanical and water vapor barrier properties of agar-based nanocomposite films. *Carbohyd Polym*. **86**: 691–699.

Ryu, S.Y., Rhim, J.W., Roh, H.J. and Kim, S.S. (2002). Preparation and physical properties of zein-coated high-amylose corn starch film. *LWT - Food Sci Technol*. **35**(8): pp. 680–68.

Seydim, A.C. and Sarikus, G. (2006). Antimicrobial activity of whey protein based edible films incorporated with oregano, rosemary and garlic essential oils. *Food Res. Int*. **39**(5): 639–644.

Shi, L, Zhou, J. and Gunasekaran, S. (2008). Lowtemperature fabrication of ZnO-whey protein isolate nanocomposite. *Mater Lett*. **62**(28): 4383-85.

Shin, Y. J., Song, H. Y., Seo, Y. B., and Song, K. B. (2012). Preparation of red algae film containing grapefruit seed extract and application for the packaging of cheese and bacon. *Food Sci Biotech*. **21**(1): 225–231.

Shon, J. and Chin, K.B. (2008). Effect of Whey Protein Coating on Quality Attributes of Low-Fat, Aerobically Packaged Sausage during Refrigerated Storage. *J Food Sci*. **73**(6): 469-475.

Downloaded by [New York University] at 14:09 23 June 2015

Sobral, P.J.A., Menegalli, F.C., Hubinger, M.D. and Roques, M.A. (2001). Mechanical, water barrier and thermal properties of gelatin based edible films. *Food Hydrocolloid*. **15**: 423-432.

Sothornvit, R. and Krochta, J.M. (2005). Plasticizers in edible films and coatings. **In**: Innovation in food packaging, Han, J.H., Ed. Elsevier Publishers, New York.

Sreenath, H. K. and Jeffries, T. W. (2011). Interactions of fungi from fermented sausage with regenerated cellulose casings. *J Ind Microbiol Biotechnol*. **38**:1793–1802.

Stemmler, M. and Stemmler, H. (1976). Composition for the preparation of coatings on meat and sausage goods. U.S. Patent 3,936,312, February 3.

Stubbs, C.A. and Cornforth, D.P. (1980) The Effects of an edible pectinate film on beef carcass shrinkage and surface microbial growth Proceedings of the 26th European meeting of meat research workers, American Meat Science Association, Louis, MO, pp. 276–278.

Stuchell, Y.M. and Krochta, J. M. (1995). Edible coatings on frozen King salmon: effect of whey protein isolate and acetylated monoglycerides on moisture loss and lipid oxidation. J Food Sci. **60**: 28-31.

Suman, S.P., Mancini, R.A., Joseph, P., Ramanathan, R., Konda, M.K.R., Dady, G. and Yin, S. (2010). Packaging-specific influence of chitosan on color stability and lipid oxidation in refrigerated ground beef. *Meat Sci*. **86**: 994–998.

Sun, Q., Sun, C. and Xiong, L. (2013). Mechanical, barrier and morphological properties of pea starch and peanut protein isolate blend films. *Carbohyd Polym*. **98**: 630–637.

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Suyatma, N.E., Copinet, A., Tighzert, L. and Coma, V. (2004). Mechanical and barrier properties of biodegradable films made from chitosan and poly (lactic acid) blends. *J Polym Environ*. **12**: 1-6.

Tahiri I., Desbiens M., Lacroix C., Kheadr E. and Fliss I. (2009). Growth of Carnobacterium divergens M35 and production of Divergicin M35 in snow crab by-product, a natural-grade medium. *LWT – Food Sci.Technol*. **42**(2): 624–632.

Tahiri, I., Desbiens, M., Benech, R., Kheadr, E., Lacroix, C. and Thibault, S. (2004). Purification, characterization and amino acid sequencing of divergicin M35: a novel class IIa bacteriocin produced by Carnobacterium divergens M35. *Int J Food Microbiol*. **97**(2):123-136.

Tanada-Palmu, P., Helen, H. and Hyvonen, L. (2000). Preparation, properties and applications of wheat gluten edible films. *Agr Food Sci Finland*. **9**: 23-35.

Walstra, P., Wouters, J. and Wageningen, T.G. (2005). Chp 2 Milk Components. **In**: book Dairy Science and technology, The Netherlands, CRC press.

Wu, Y., Geng, F., Chang, P. R., Yu. J. and Ma, X. (2009). Effect of agar on the microstructure and performance of potato starch film. *Carbohyd Polym*. **76**(2): 299–304.

Xu, X.Y., Kim, K.M., Hanna, M.A. and Nag, D. (2005). Chitosan-starch composite film: preparation and characterization. *Ind Crops Prod Int J*. **21**:185-192.

Yoon, S and Deng, Y. (2006). Clay–starch composites and their application in paper-making. *J Appl Polym Sci*. **100**(2):1032–8.

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Zahedi, Y., Ghanbarzadeh, B. and Sedaghat, N. (2010). Physical properties of edible emulsified films based on pistachio globulin protein and fatty acids. *J Food Eng*. **100**: 102–10.

Zhou, J.J., Wang, S.Y. and Gunasekaran, S. (2009). Preparation and characterization of whey protein film incorporated with TiO2 nanoparticles. *J Food Sci*. **74**(7): 50-56.

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Table1: Various protein based films and coatings used on meat and meat products as a packaging material.

Type of Protein	Products Used	Effect	References
Soy protein with ferulic acid	Lard	Antioxidant effect	Ou et al., 2005
Whey protein isolates and calcium caseinates with glycerol with oregano /pimento oils	Beef muscle slice	Antioxidant effect	Oussalah et al., 2004
Whey protein isolates and glycerol with grape seed extract	Turkey frankfurters	Antimicrobial effect	Gadang et al., 2008
Pectin and green tea with irradiation	Pork patties	Reduced lipid oxidation and enhanced shelf life.	Kang et al., 2007
Whey protein, sorbitol and carboxymethylcellulose	Low fat sausages	Prevented moisture loss and had antimicrobial effect	Shon and Chin 2008
Sodium caseinate and glycerol	Cooked turkey meat	Reduced lipid oxidation	Caprioli et al., 2009
Pea starch based film with grape seed extract	Pork loin	antimicrobial	Corrales et al., 2009

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Table 2: Polysaccharide based film and their application in meat products preservation

Polysaccharides	Products	Effect	References
Chitosan with cinnamon oil	Cold stored trout fillet	Reduced lipid oxidation and enhanced shelf-life	Ojagh et al., 2010
Chitosan coating	Herring and cod fillets	enhanced shelf life	Jeon et al., 2002
Chitosan coating with Vitamin E	Lingcod fillets	Antioxidant effect	Duan et al., 2010
Hydroxypropylmethyl cellulose	Deep fried chicken meat balls	Increased moisture retention and reduced fat absorption	Balasubramaniam et al., 1997
Calcium pectinate gel	Beef plates	Reduced shrinkage	Stubbs and Cornforth, 1980
Pectin film containing green tea	Pork patties	Decreased lipid oxidation	Kang et al., 2007
Alginate	Meat patties	TBA, tyrosine value, sensory quality	Chidanandaiah et al., 2009
Agar	Poultry & beef	Extend the self-life of products	Cutter 2006
Carrageenan	Poultry meat	Increased self-life	Meyer et al., 1959

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Table 3: Application of lipid based film on meat and meat products preservation

Lipid film	**Products**	**Function**	**Reference**
Fat	Meat patties & sausages	Enhanced shelf-life	Kroger and Igoe, 1971
Fat	Freshly cut meat	Superior in colour and moisture retention	Letney, 1958
Carnauba and bee wax	Frozen meat	Extended shelf-life	Cutter and sumner 2002
Lipid based film	Pork and Beef cuts	Prolong the colour, aroma, tenderness and microbial quality	Stemmler and Stemmler 1976
Acetoglycerides	Meat products	Reduce off-flavour, prevent moisture loss and freezer burns	Anderson 1960
Acetylated monoglyceride	poultry and meat cuts	Retarded moisture loss during storage	Kester and Fennema, 1986

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Table 4: Application of active film in preservation of meat and meat products

Film	Active component	Product	Effect	Reference
Gelatin film	Borage extract	Frozen fish patties	Reduced lipid oxidation	Gimenez et al., 2011
Pullulan film	2% oregano, 2% rosemary	Vacuum-packed and refrigerated raw turkey breast, raw beef	Reduced microbial count	Morsy et al., 2014
Chitosan film	CH CH-LAE	Chicken breast fillet	Low microbial load on storage	Higueras et al., 2013
Red Algae Film	Grape seed extract (1%)	Bacon	Effective in controlling *E.coli* O157:H7 and *L.monocytogenes* growth	Shin et al., 2012
Chitosan Film	Nisin and Lauric arginate	Sliced turkey deli meat	Reduction in microbial counts	Guo et al., 2014

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Table 5: Advantage and disadvantage of edible film

Advantages of edible films	**Drawbacks of edible films**
Edible films are environment friendly	Poor mechanical properties
Enhance organoleptic properties like colour, appearance	cannot be used alone as individual packaging a secondary packaging is must
Enhance nutritional values by supplementation	Presently costly
Films can be used as carrier of antioxidants or antimicrobials	Even a small degree of irregularity in a film can exponentially increase rate of diffusion (Gontard et al. 1996)
Effective utilization of industrial by-products	Sometimes off-odours may develop
Reduce the waste and solid disposal problem	decompose more rapidly or lose their quality and integrity faster (oxidation, dissolution, etc.) than those of synthetic origin

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