



# Materiality of Edible Film Packaging in Muscle Foods: A Worthwhile Conception

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Received: 12 September 2019 / Accepted: 7 February 2020 / Published online: 20 February 2020  
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## Abstract

Muscle foods are extremely extensive food products that are relished throughout the world. They are known for their exclusive nutritional content and bio-availability however, at the same time, they also provide apposite media for the growth of pathogenic and spoilage microorganisms. Packaging seems to be a substantial approach to overcome this problem, but most of the packaging involves the usage of non-biodegradable and non-renewable material like plastic, nylon, polyester, etc. The alarming situation caused by synthetic material has been realized worldwide and several scientists, agencies, and the food industry are working globally to explore materials that are derived from the natural source. Biodegradable films are an excellent alternative to conventional plastics. These biodegradable films and coatings are derived from various biological sources and are receiving considerable importance in recent years. Different meat and meat product needs specific packaging condition and these active, composite bio-based films are having a wide potential in the meat sector. This review gathers the research and findings over the period of time-related to biodegradable edible film applied to muscle foods.

**Keywords** Edible film · Antimicrobial · Essential oil · Lipid-oxidation · Meat spoilage

## Introduction

Globally meat-food sector plays an imperative role in countries' well-being as it not only caters the requirement of meat and edible by-products for human consumption, but also confers sustainable livestock development and subsistence security for millions of men and women from weaker sections. On account of supportive socio-economic factors such as changing eating habits, better purchasing power, urbanization, increasing apprehension towards protein-rich diet, there has been increasing in demand for meat and the sector has attained significant meaning in terms of contribution to income, employment and foreign exchange earnings [26].

Since meat and meat products are having the richest nutritional matrix, its superiority is extremely prone to degradation due to digestive enzymes, microbial spoilage and lipid oxidation [140]. Distinctive technical operations are involved in the conversion of muscle to meat; inadequacy at any stage will result in a rigorous negative impact on the product and/or process in the following stage. Besides hygiene and storage temperature, the acidity of the meat and the structure of the muscular tissue influence the degree of spoilage as well. Lipid oxidation, protein degradation and the debt of other important molecules are the results of meat spoilage progression. This deleterious break down of fat and protein is instigation for the production of contingent compounds eliciting changes in meat flavor, tenderness, juiciness, odor, texture and appearance. It is, therefore, necessary to prevent spoilage of meat and meat products to prolong the freshness of these muscle foods.

One customary way to overcome these problems along with the extension of the shelf life of such food is through packaging. Meat packaging once used principally as an inert barrier to protect its contents against contamination moreover this purpose has shifted towards harmonizing functions that complement product quality, permanence and customer/retail presentation and be eco-friendliness.

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On this perspective use of bioactive food packaging to extend shelf life and safety of perishable food, particularly those susceptible to the microbial and chemical downturn, have gained noticeable interest. During the last three decades, considerable effort has been made by researchers/industries studying packaging, materials, food processing, and biotechnology to design active food packaging materials together with creating awareness of going green. A newer concept dedicated to preserving the environment following the awareness of the amount of nonessential plastic waste produced from packaging goods is emerging. Moreover, the work done for antimicrobial and antioxidant effects of essential oil on such starch-based edible film for meat is scantily available. Therefore, realizing the need of alternative packaging techniques and enhancement for food safety using natural sources, this review is written to exhibit the well-being of biodegradable packaging beyond traditional packaging.

## Meat Sustenance and Vulnerability for Deterioration

Nutrient richness makes meat, the first-choice source of animal protein to the consumer throughout the world [76]. Meat has conferred a crucial role in human evolution and is an influential section of a healthy and well-balanced diet. Muscle foods constitute a good nutrients source for diet, where their protein provides high biological value and essential amino acids which complement the quality of cereals and other vegetable proteins [182]. The important micronutrients are also best available from meat, e.g. Iron selenium and vitamin A and B<sub>12</sub> and folic acid either because they do not exist in plant-derived food or because they are poorly available. Meat fat comprises mostly monounsaturated and

saturated fatty acid with oleic, palmitoleic and stearic acid being the most ubiquitous. Such type of nutritionally condensed food is very much susceptible to chemical (oxidation) and microbiological (spoilage) deterioration and therefore represents a high risk for consumer health [76].

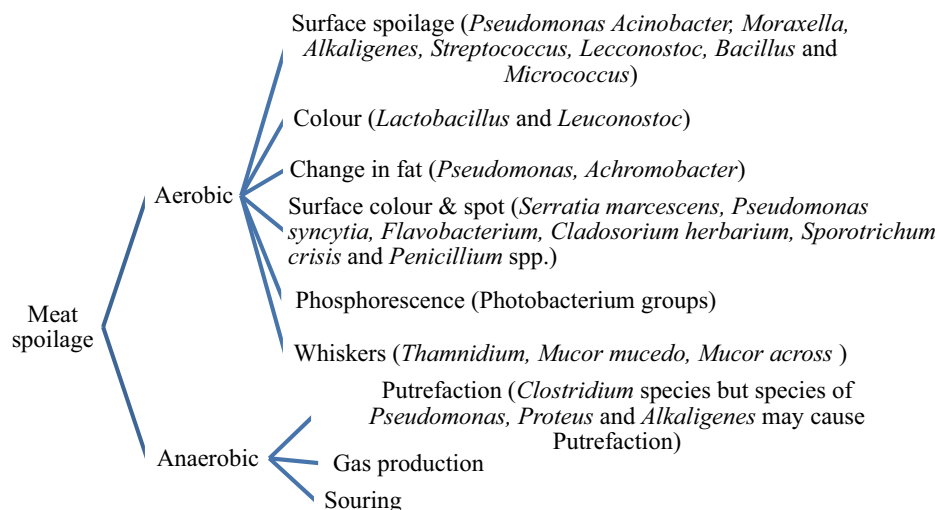
## Microbial Degradation

Pre-slaughter handling of livestock and post-slaughter handling of meat play an important part in the deterioration of meat quality [41]. Microbes can be responsible for the spoilage of food when they breakdown the meat, acids and other meat waste products are created in the process. As the microbes itself may or may not be harmful, the waste products may be unpleasant to taste or may even be harmful to one's health. A common type of microbial spoilage of meat can be classified based on whether they occur under aerobic or anaerobic conditions and whether they are caused by bacteria, yeast or mold (Fig. 1).

In meat, pathogenic micrograms, specifically *Campylobacter*, *Salmonella* spp. (raw or undercooked meat particularly poultry), *Staphylococcus aureus*, *Listeria monocytogenes* (chilled, “ready-to-eat” foods, including pre-packed sandwiches, cooked sliced meats, and pâté), *Clostridium perfringens*, *Clostridium botulinum*, and *Escherichia coli* O157:H7 are of major concern as their presence not only deteriorate the quality but also gravitate to food safety issues [88].

Several studies already established that meat is most perishable of all foods [139, 144, 173]. The nutritional matrix and moist surface make it conducive to the colonization and growth of a wide range of spoilage bacteria. This has been described as loose and reversible sorption [48]. The next and irreversible stage of attachment involves the production of a sticky polysaccharide extracellular layer by the bacterium,

**Fig. 1** Microbial spoilage in meat



called the glycocalyx [40], that ultimately leads to the production of biofilm. This colonization is responsible for a change in the organoleptic property of meat that too varies according to species of colonizing bacteria, type of processing and storage condition of meat.

Meat borne diseases impede socioeconomic development by straining health care systems, harming national economies, tourism and trade. The situation becomes further susceptible with the implementation of GATT as food supply chains now cross multiple national borders.

## Lipid Peroxidation

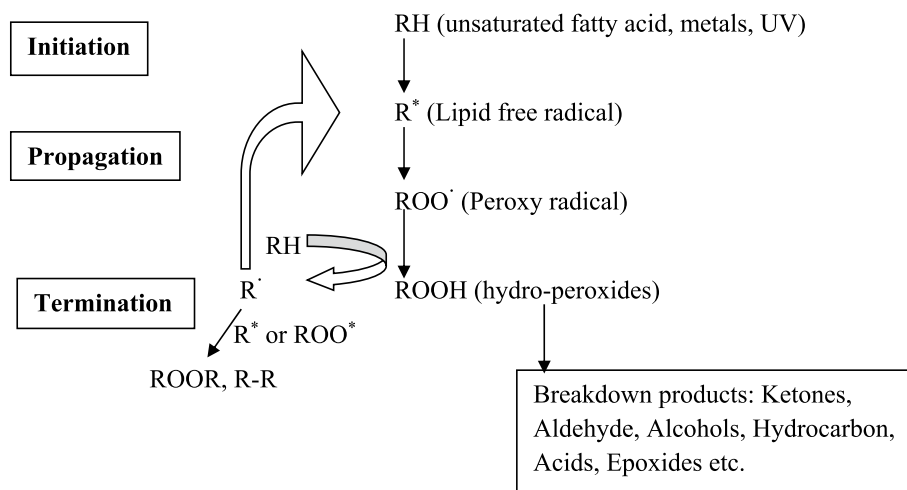
Modern consumer concerns over “Quality” and “healthfulness” by meat products have greatly changed during past decades. Sensory quality characteristics viz. appearance/color, texture, and flavor are the main quality attributes that affect consumer acceptance of meat, and lipid peroxidation is the primary cause of these quality deteriorations in meat and meat products. Lipid oxidation is relatively a complex process whereby unsaturated fatty acids reacting with molecular oxygen via a free radical chain mechanism, form fatty acyl hydroperoxides, commonly called peroxides or primary products of the oxidation [110]. The primary auto-oxidation is followed by a series of secondary reactions that lead to the degradation of the lipid and the development of oxidative rancidity [46]. The problems associated with lipid oxidation have gained much interest as they relate to flavor deterioration, loss of nutritional value and safety, biological damage, aging, functional property changes, and environmental pollution. The off-flavors associated with oxidation are attributed to a number of different hydroperoxides which, in conjunction with the many different decomposition pathways involved, lead to a large number of volatile compounds [45]. Although the organoleptic aspects of lipid oxidation were considered, until recently, to be the most important to

both producer and consumer, great attention has now been given to health risks that lipid oxidation might impose. Lipid hydroperoxides and their decomposition products may cause damage to proteins, membranes and biological components, thus affecting vital cell functions [117]. Products of lipid oxidation process are voted as chemical toxicants and are believed to lead to deteriorative processes in man, including aging [168]. Lipid peroxides and oxidized cholesterol may be involved in tumor promotion and atherosclerosis, whereas malonaldehyde, a secondary product of lipid oxidation, has been implicated as a catalyst in the formation of *N*-nitrosamines and also as causing mutagenesis [110]. Refrigerated and frozen fresh meats are also susceptible to lipid oxidation and cooking makes them more vulnerable (Fig. 2). The process such as grinding, cooking and deboning (disrupting the muscle membrane system), results in exposure of the labile lipid components to oxygen and consequently accelerates the rancidity. As consumption of prepackaged raw meat and precooked is significantly increasing, control of oxidation has become ever more important. Realizing the problems associated with oxidation, a lot of work has been done to prevent rancidity in muscle foods and is still being carried out throughout the globe. The growing concerns of the consumer about the possible health risks from the use of additives in foods, the use of natural antioxidants have eventually gained importance.

## Containment of Muscle Food

Packaging is an accessional characteristic that is gaining substance as a compulsory tool for meat quality maintenance. The purpose of any packaging system for muscle foods is to prevent or delay undesirable oxidative and microbiological deteriorative changes to the appearance, flavor, odor, texture and to extend the shelf life of the product [159]. Packaging

Fig. 2 Auto-oxidation of meat



plays a more crucial role in meat and meat products as they deteriorate much faster and possess a higher potential for contamination as compared to other foods. Practically, the films used for meat packaging derive from synthetic “plastic” materials [76]. The most commonly used polymers for food packaging are low-density polyethylene, high-density polyethylene, polypropylene, and polyamide [85] polyesters, polyvinylidene chloride, polystyrene and ethylene/vinyl acetate [121]. Contrasting packaging material has its advantages, disadvantages, consumer and marketing issues, and environmental considerations.

Polymers and plastics are typical materials of the last century and the continuous innovation around them helps to explain that since 1950, plastics production has increased by an average of almost 10% every year on a global basis [145]. The polymers and materials used for food-packaging today consist of a variety of petroleum-derived plastic materials [187], metals, glass, paper, and board, or combinations thereof, because of their availability in large quantities at low cost and favorable functionality characteristics. Except for paper and board, all major packaging materials are based on non-renewable materials [81], implying that at some point, more alternative packaging materials based on renewable resources have to be found to avoid problems concerning waste disposal [183]. Environmental devaluation and depreciation of fossil fuels provoked the use of renewable resources [60].

### Current Disposal Statistics of Plastic

Global production of resins and fibers increased from 2 Mt in 1950 to 380 Mt in 2015, a compound annual growth rate of 8.4% [146]. The biggest groups in total non-fiber plastics fabrication are PE (36%), PP (21%), and PVC (12%), followed by PET, PUR, and PS (< 10% each). Polyester, most of which is PET, accounts for 70% of all PP&A fiber production. Collectively, these seven groups account for 92% of the usual plastics manufactured [62].

However, most synthetic films are petrochemical-based and non-biodegradable; it takes several hundred years to degrade synthetic plastics [75] which has caused a very detrimental impact on the environment throughout the globe [136]. The growing consumer demand for healthier products that do not cause environmental pollution has led to a change in the approaches used for the manufacture of materials by the food packaging industry [159]. Natural polymers are now, progressively searched as packaging materials due to their eco-friendly nature.

Biodegradable films are the excellent alternative to conventional plastic or even biodegradable plastic in food industries. These biodegradable films and coatings can be prepared from various biological polymers such as

polysaccharides, proteins or lipids and are receiving considerable importance in recent years. These films and coatings can protect a food product by serving as barriers to moisture migration, and preventing diffusion of gases important in food deterioration, such as O<sub>2</sub> or CO<sub>2</sub> [87, 107]. They can also enhance the quality and appearance of a food product by preventing flavor and aroma migration and by providing structural integrity.

### History of Edible Film and Coatings

Edible films and protective coatings have been used for centuries to prevent quality loss such as shrinkage, oxidative off-flavors, microbial contamination, and discoloration in meat and poultry products [84]. Yuba, the first free-standing edible film, was developed in Japan from soymilk during the fifteenth century and was used for food preservation purposes [28]. In the sixteenth-century England, cut meats were coated in fats to reduce moisture loss and, thus, shrinkage in a process called “larding” [99]. Since then, a number of lipid coating formulations have been used to enhance the quality of meat and meat products. Letney [115] proposed coating meat with melted fat and letting it solidify to form a film to extend the storage life of meat products during refrigerated storage and maintain “bloom”. Carnauba wax, beeswax, and candelilla have been used to coat frozen meat to increase its shelf life [44]. Use of acylated acylglycerol containing chlortetracycline [13], mixtures of mono-, di- and triacylglycerols in alcohol [6, 7] and acetylated mono- and diacylglycerol coatings have been suggested to reduce off-flavors and moisture loss, as well to maintain color and prevent freezer-burn in meat products. Applications of paraffinic acid mono-, di- and triacylglycerol with or without carboxylic acid have also been reported to improve meat quality and storage life [160]. Griffin et al. [69] reported the application of acetylated mono acyl glycerol in vacuum-packed meats. Emulsion coatings containing lipids have also been demonstrated to be useful in enhancing meat quality [18]. Collagen films and sausage casings are probably the most successful commercial application of edible films in meat products [125].

### Edible Coating and Film

Edible film is defined as thin, continuous or unbroken sheets made up of edible substances [16, 70]. Natural polymers like lipids and protein are used to produce environmental friendly edible films [123]. Edible packaging film and coatings are not generally meant to entirely replace conventional packaging, rather the efficiency of food preservation can be further improved by using primary edible packaging together with non-edible packaging as secondary packaging

to add additional protection from the atmosphere and prevent contamination from microorganisms or foreign contaminants [112]. These films can be placed in between food elements, act as a food wrapper and a pocket to hold food [77]. Edible packaging generally consists of edible films, sheets, coatings, and pouches. Edible films (thickness < 254  $\mu\text{m}$  or 10 mil) or sheets (thickness > 254  $\mu\text{m}$ ) are stand-alone structures that are preformed separately from the food and then placed on or between food components or sealed into edible pouches [108], whereas edible coatings are thin layers of edible materials formed directly onto the surface of the food products.

The main advantage of edible films over traditional synthetics is that they can be consumed with the packaged products [87]. There is no package to dispose of even if the films are not consumed they could still contribute to the reduction of environmental pollution. The films are produced exclusively from renewable, edible ingredients and therefore are anticipated to degrade more readily than polymeric materials [30]. The main role of edible coatings is to preserve the high quality of a food product [118, 180]. Edible films can extend the shelf life of processed food by providing barrier to moisture, gas, and lipid, as well as protection [86]. The films can enhance the organoleptic properties of packaged foods provided they contain various components (flavorings, colorings, sweeteners) [30].

Fresh meat requires oxygen for maintaining color and cured meats degrade in the presence of oxygen. These two parameters are significant while selecting packaging material i.e. shape or form and material. The film-forming solution is pretty cable of being molded to get a film of said characteristics. In addition, since the water activity ( $a_w$ ) is critical for microbial, chemical, and enzymatic activities, Cha and Chinnan [36] demonstrated that films can resist the migration of moisture into the meat or poultry during the storage. Edible films and coatings can also serve as carriers for antimicrobials, antioxidants, nutrients, color,

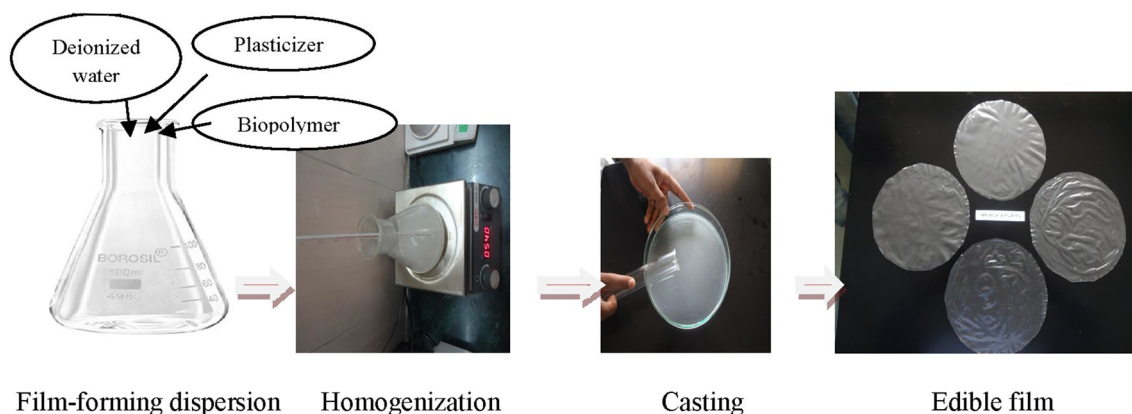
herbs, and spices, and provide for localized or delayed activity if needed.

The utilization of edible packaging can reduce the complexity of overall packaging requirements by allowing conversion from multilayer or multilevel packaging to a single-component package, resulting in source reduction and improved recyclability [102] of the simplified packaging system without compromising protective functions [107]. Edible Films and Coatings in accordance with good manufacturing practices must typically have the approval of the Food and Drug Administration (FDA) as Generally Recommended as Safe (GRAS) items [8] (Fig. 3).

## Biopolymers

Components of edible films can be divided into three categories: hydrocolloids, lipids, and composites. Hydrocolloids include proteins and polysaccharides, such as starch, alginate, cellulose derivatives, chitosan, and agar. Lipids include waxes, acylglycerols, and fatty acids [126]. Composites contain both hydrocolloid components and lipids [5]. The choice of formulation for biopolymers is largely dependent on its desired function such as aesthetic appearance and good barrier properties against oxygen [36].

Structuring biopolymers, polysaccharides such as chitosan [53], hemicelluloses [74] and starch [89], proteins [151], and lipids [49] have been used for the formulation of edible films for meat. Gelatin is a denatured protein derived from collagen by thermal hydrolysis [111] possesses excellent film-forming and barrier properties against oxygen and light [2]. Sodium caseinate, a mixture of casein monomers and small aggregates [166] formed after the removal of colloidal calcium phosphate from casein micelles has been found suitable by Pankaj et al. [135] for packaging of meat.



**Fig. 3** Preparation of edible film (Source: [25])

## Polysaccharide-based Films

Polysaccharides are most often used for edible films because their film-forming properties are derived from starch, alginate, dextrans, pectin, chitosan, carrageenans and their mixtures [73]. These are non-toxic, widely available, selectively permeable to CO<sub>2</sub> and O<sub>2</sub> and are hydrophilic in nature. For this reason, these films are poor barrier to water vapor [131] and allow movement of water vapor across the film, thus, preventing water condensation that can be a potential source of microbial spoilage [36].

### Starch

Edible or biodegradable starch films primarily derived from cereal grains, potatoes, tapioca, or arrowroot starch or its components, amylose and amylopectin, by two main techniques: solution casting and subsequent drying (wet method) and thermoplastic processing (dry method) [134]. Amylose is a nearly linear polymer of  $\alpha$ -1,4 anhydroglucose units [33, 116]. Amylose content of starch is responsible for its film-forming capacity [39]. Starch containing high amylose produces films with higher flexibility, oxygen impermeability, oil resistance; heat-seal ability, and water solubility. Films of high-amylose corn starch or potato starch was more stable during aging [109]. Starch-based films display similar physical characteristics to plastic films as that they are also odorless, tasteless, colorless, transparent [89], non-toxic, biologically absorbable, semi-permeable to carbon dioxide, and resistant to the passage of oxygen. Mohan et al. [127] used *S. aromaticum* and *C. cassia* fused starch edible films to enhance shelf life of mutton (*Capra aegagrus hircus*) meat. Tosati et al. [177] found a significant antimicrobial effect of edible coating based on turmeric starch residue and gelatin onto fresh frankfurter sausage. Bhattacharya and Kandeepan [27] did the selection of biopolymers to develop a biodegradable and edible film for packaging of luncheon chicken meat slices. Alotaibi and Tahergorabi [4] developed sweet potato starch-based coating to enhance the quality attributes of shrimp during refrigerated storage. Development of potato starch based active packaging films loaded with antioxidants and its effect on shelf life of beef was done by Nisa et al. [130].

### Carrageenan

Carrageenan is a collective term used to express 'polysaccharides' that are extracted from certain species of red seaweed of the *Rhodophyceae* family. Carrageenans are anionic linear sulfated polysaccharides composed of D-galactopyranose residues bonded by regularly alternating a-(1/3) and b-(1/4) bonds. k-car is the most commercially used carrageenan out of the three main types of carrageenans, the

others being i-carrageenan and l-carrageenan. k-car contains one negatively charged sulfate group and has 3,6-anhydro-D-galactopyranose residues in the chain that impart k-car the ability to form gels [174].

Polysaccharide-based coatings including carrageenan have good gas barrier properties [137]. Carrageenan, as edible films and coatings have already covered various fields of the food industry such as an application on fresh and frozen meat, poultry and fish to prevent superficial dehydration [165], sausage-casings [143]. Bharti [25] developed and characterized essential oils incorporated starch and carrageenan based edible film for packaging of chicken nuggets.

### Chitosan

Chitosan is the second most abundant natural and non-toxic polymer in nature after cellulose and is mainly made from crustacean shells. In industrial processing, chitin is extracted by acid treatment to dissolve the calcium carbonate followed by an alkaline solution to dissolve proteins. In addition, a decolorization step is often added to remove pigments and obtain colorless pure chitin [188]. Chitosan films are advantageous as it forms films without the addition of additives, exhibits good oxygen and carbon dioxide permeability along with excellent mechanical and barrier properties [55]. Chitosan also exhibits strong antimicrobial activity against bacteria, yeasts and molds [71].

Chitosan films prepared with oregano essential oil were applied to bologna slices and suggested as an antimicrobial packaging material for processed meat [37]. Karimnezhad et al. [97] showed enhanced antimicrobial effects of chitosan-based edible film containing *Trachyspermum ammi* essential oil on shelf-life of chicken meat and *Thymus vulgaris* L. essential oil [148] in ready-to-eat meat. The sensory, physicochemical and microbiological quality of pastirma (a traditional dry-cured meat product) was improved by using chitosan coating [1]. Chitosan-based nanofibers films show in situ bioactivity against *E. coli* as a bioactive barrier to meat contamination [9] developed as bioactive meat packaging materials.

### Alginates

Alginates are derived from brown seaweed (commercially from *Macrocystis pyrifera*, *Laminaria hyperborea*, *Laminaria digitata*, and *Ascophyllum nodosum*) and, in the presence of divalent cations, producing films that are particularly useful for applications that enhance the quality of meat and poultry products [131]. Calcium is the most common and effective divalent cation in gelling alginates, though magnesium, manganese, aluminum, ferrous, or ferric ions are also used [99]. Alginate film strength may further be improved in the presence of modified starches, oligosaccharides or

simple sugars [61]. Raeisi et al. [149] found the improved microbial quality of chicken meat with sodium alginate coating incorporated with nisin, *Cinnamomum zeylanicum*, and rosemary essential oils on the fate of *Listeria monocytogenes* during refrigeration. Vital et al. [179] found the superiority of alginate-based edible coating containing natural antioxidants (rosemary and oregano essential oils) on lipid oxidation, color perseverance, water losses, textural profile and pH of beef steaks.

### Protein-based Films

Film-forming proteins are derived from animals (casein, whey protein concentrate and isolate, collagen, gelatin, and egg albumin) or plant sources (corn, soybean, wheat, cottonseed, peanut, and rice). Protein-based films adhere well to the meat hydrophilic surfaces and provide a barrier for oxygen and carbon dioxide but do not resist water diffusion [42]. Films prepared from proteins and carbohydrates are excellent barriers to oxygen, because of their tightly packed matrix and ordered hydrogen-bonded network structure [187].

Plasticizers, such as polyethylene glycol or glycerol, are added to improve flexibility of the protein network, whereas water permeability can be overcome by adding hydrophobic materials such as beeswax or oils like oleic that can affect films properties such as crystallinity, hydrophobicity, surface charge, and molecular size, improving films characteristics and their application [80]. Despite so many advantages, protein films may be susceptible to proteolytic enzymes present in meat products or allergenic protein fractions, which may cause adverse reactions to the sensitive populace [61].

Yang et al. [186] found improved antioxidant activities of distiller dried grains with solubles as protein films containing tea extracts in the packaging of pork meat. Akcan et al. [3] found antioxidant protection of cooked meatballs during frozen storage by whey protein edible films containing phytochemicals from *Laurus nobilis* L. and *Salvia officinalis*. Gallego et al. [59] developed gelatine-based antioxidant packaging containing *Caesalpinia decapetala* and Tara as a coating for ground beef patties. Catarino et al. [35] found the improved performance of whey protein active coatings with *Origanum virens* essential oils in the quality and shelf-life improvement of processed meat products. Antioxidant active packaging with soy edible films and oregano or thyme essential oils for oxidative stability of ground beef patties [104].

### Lipid-based Films

A wide range of hydrophobic compounds has been used to produce EFC, including animal and vegetable oils and fats (peanut, coconut, palm, cocoa, lard, butter, fatty acids, and mono-, di- and triglycerides), waxes (candelilla, carnauba,

beeswax, jojoba, and paraffin), natural resins (chicle, guarana, and olibanum), essential oils and extracts (camphor, mint, and citrus fruits essential oils), and emulsifiers and surface-active agents (lecithin, fatty alcohols, and fatty acids) [49].

Films composed of lipids have good water vapor barrier properties but exhibit reduced mechanical strength and increased oxygen permeability. When such ingredients are combined, they could physically and/or chemically interact and may result in films with improved properties [50]. To conquer the poor mechanical strength of these films, they can be used in combination with hydrophilic materials using the formation of an emulsion or through lamination with a hydrocolloid film lipid layer [29]. Karbowski et al. [95] validated that the efficiency of an edible film against moisture transfer cannot be simply enhanced by the addition of hydrophobic materials in the formulation unless the formation of a homogeneous and continuous lipid layer inside the hydrocolloid matrix is achieved. Fabra et al. [56] and Jimenez et al. [90] found that fatty acids can form stable layers in film matrices, whose properties depend on their chain length i.e. the lower the chain length, the greater the layers.

In meat products, emulsifiers and surface-active agents are sometimes used as gas and moisture barriers. However, pure lipids can be combined with hydrocolloids such as protein, starch, cellulose, and their derivatives providing a multi-component system able to be applied as meat coatings [42]. Gennadios et al. [61] found that lipid incorporation into edible film coating can improve hydrophobicity, cohesiveness, and flexibility, making excellent moisture barriers, leading to prolongation of freshness, color, aroma, tenderness, and microbiological stability in fresh and processed meats.

### Composite Edible Films

Multi-component or composite EF has been optimized attending to its mechanical properties and transparency, looking for consumer's acceptability and for the ability to withstand mechanical stress and handling during the transport [133]. Sabina and Andrzej [155] found superior composite films prepared by casting sodium alginate and low methoxy pectin. However, when lipids are added for improving moisture barrier properties, other features such as transparency can be affected [90].

### Nanocomposite Film

The use of bio-nano composite materials for edible packaging promises to improve barrier and mechanical properties beyond what could be achieved by utilizing macroscopic reinforcing components [15]. Nanocomposite coatings demonstrate materials of a new generation that composed of at least two phases

along with a nanocrystalline and/or amorphous component [175]. Simply, nanocomposite coating is a matrix composed of at least two immiscible phases, separated from one another by interface region. Accordingly, the material must contain the nanometer scale in at least one dimension in which the major component is dispersed [129]. The uniform dispersion of nanoparticles causes the formation of a very large matrix/filler interfacial area, which changes the nanostructure, molecular mobility, relaxation behavior, and the consequent thermal and mechanical properties of the final film [43]. Furthermore, the nanocomponents are expected to improve barrier properties by increasing the tortuosity of the path that water, gases, or low-molecular-weight compounds take to penetrate the films [47].

Sani et al. [157] developed a nanocomposite film of Whey protein isolate/cellulose nanofibre/TiO<sub>2</sub> nanoparticle/rosemary essential oil and found enhanced microbial and sensory quality of lamb meat during refrigeration storage. Zhang et al. [190] characterized microemulsion nanofilms based on Tilapia fish skin gelatine and ZnO nanoparticles incorporated with ginger essential oil and found reduced antioxidant property towards lipid oxidation during storage.

## Roles of Plasticizer

Plasticizers are low molecular weight non-volatile [161], high boiling point liquids with average molecular weights of between 300 and 600, and linear or cyclic carbon chains (14–40 carbons) [51, 184] additives used to increase the flexibility or plasticity of polymers, and occasionally used only to facilitate the polymer processing. The most commonly used plasticizers in starch-based films are polyols, such as sorbitol and glycerol [38]. They are frequently added into edible films to reduce the intermolecular forces and increase the mobility of the polymeric chains, intersperse and intercalate among and between polymer chains, disrupting hydrogen bonding and spreading the chains apart, which not only increases flexibility [52], but also water vapor and gas permeabilities [17, 171]. Glycerol is often used to modify the mechanical properties [124] of hydrophilic films. With increasing concentration of glycerol into films, there is a reduction in internal hydrogen bonding between polymer chains while an increase in molecular volume, resulting in improved film flexibility [120].

## Use of Antimicrobials and Antioxidant in Edible Film

Quite recently, the idea of incorporating antimicrobial agents directly into packaging films has been developed. Thus, the packaging material can serve as a source of releasing preservatives or antimicrobial agents or even prevent the growth of microorganisms. Several antimicrobial

compounds viz. organic acids (acetic, propionic, benzoic, sorbic, lactic, lauric), potassium sorbate, bacteriocins (nisin, lacticin), grape seed extracts, spice extracts (thymol, *p*-cymene, cinnamaldehyde), thiosulfonates (allicin), enzymes (peroxidase, lysozyme), proteins (conalbumin), isothiocyanates (allylisothiocyanate), antibiotics (imazalil), fungicides (benomyl), chelating agents (EDTA), metals (silver), or parabens (heptylparaben) can be added to edible films to reduce bacteria in solution, on culture media, or a variety of muscle foods. The incorporated antimicrobial agents must be edible food-grade compounds since they have to be consumed along with the edible gels, films, or coatings [41, 72].

The addition of antioxidants is a traditional method of controlling oxidative deterioration in meats and meat products [11]. One promising approach for optimizing effective usage of these antioxidants is active packaging with the incorporation of active substances into food packaging materials [128]. Research in this area has been directed toward utilization of biodegradable packaging materials because of the negative environmental impact of plastics; thus, attention has been paid to edible films (EF) and coatings that can serve as good carriers for many food additives, including antioxidants [147]. There is limited research on antioxidant active packaging for food applications using EFs and coatings [104, 132].

## Essential Oil

Essential oils derived from natural sources have been added to the film as an antimicrobial agent [141]. Essential oils categorized as GRAS (generally recognized as safe) by US Food and Drug Administration [142]. Several new studies have been conducted to observe the effects of EOs obtained from sources such as rosemary, oregano, thyme, sage, basil, ginger, turmeric, coriander, garlic, nutmeg, clove, mace, savory, and fennel, when used alone or in combination with other EOs and/or preservation methods, to improve the sensory qualities and extend the shelf life of meat and meat products [10, 67].

The ability of plant essential oils to protect foods against pathogenic and spoilage microorganisms has been reported by several researchers [31, 58, 152]. To achieve an effective antimicrobial activity in direct food applications, high concentrations of essential oils are generally needed, which might impact inappropriate flavors and odors in the product [163]. Various spices and essential oils have preservative properties and have been used to extend the storage life of meat products for instance eugenol in cloves and allyl isothiocyanate in mustard seed [156].



**Table 1** Essential oil incorporated edible film for antimicrobial property

Film	Essential oil	Substrate	References
Skate skin gelatin films	Thyme essential oil	Chicken tenderloin	Lee et al. [113]
Sodium alginate coating	<i>Cinnamomum zeylanicum</i> , and rosemary essential oils	Chicken meat	Raeisi et al. [149]
Sodium alginate	Rosemary and oregano essential oils	Beef	Vital et al. [179]
Plantago major seed mucilage	<i>Anethum graveolens</i> essential oil	Beef	Behbahani et al. [22]
Carrageenan	Oregano and thyme essential oils	Chicken patties	Soni et al. [170]
Chitosan-based	Clove oil	Cooked pork sausages	Lekjing [114]
Chitosan films	<i>Thymus vulgaris</i> L. essential oil	Ready-to-eat meat	Quesada et al. [148]
Whey protein edible films	Phytochemicals from <i>Laurus nobilis</i> L. and <i>Salvia officinalis</i>	Cooked meatballs	Akcan et al. [3]
Chitosan	Cumin and eucalyptus essential oils	Fresh chicken meat	Sharafati Chaleshtori et al. [164]
κ-carrageenan	Procyanidin	Pork loin meat	Kim et al. [103]
Cassava starch films	Oregano essential oil	Ground beef	Caetano et al. [32]
Polylactic acid films	Lemongrass oil	Pork sausages	Yang et al. [186]
Active starch biopolymeric packaging film	Essential oil of <i>Syzygium aromaticum</i>	Sausages	Ugalde et al. [178]
Chitosan coating	<i>Cinnamomum zeylanicum</i> oil	Chicken meat nuggets	Khare et al. [100]
Carrageenan	Cinnamon oil	Chicken fillets	Khare et al. [101]
Chitosan film	Anise ( <i>Pimpinella anisum</i> L.) essential oil	Chicken burger	Mahdavi et al. [119]
Microemulsion nanofilms based on Tilapia fish skin gelatine:	Ginger essential oil	Meat	Zhang et al. [190]
Sodium alginate coatings	Green tea	Chicken nuggets	Kristam et al. [106]
Sweet potato starch coating	Thyme oil	Shrimp	Alotaibi and Tahergorabi [4]
Soy edible films	Oregano or thyme essential oils	Ground beef	Kodal Coşkun et al. [104]
Chitosan edible films	<i>Thymus moroderi</i> and <i>Thymus piperella</i> essential oil	Cooked cured ham	Ruiz-Navajas et al. [154]
Chitosan coatings	Garlic oil	Shrimp	Aşık and Candoğan [12]
Chitosan films	Cinnamon and ginger	Pork	Wang et al. [181]
Whey protein active coatings	<i>Origanum virens</i> essential oils	Processed meat products	Catarino et al. [35]
Sodium alginate edible films	Oregano essential oil	Ham slices	Pavli et al. [138]
Chitosan-montmorillonite bionanocomposites	Rosemary essential oil	Fresh poultry meat	Souza et al. [172]
Chitosan-based edible film	Oregano essential oil	Fresh chicken meat	Karimnezhad et al. [96]
Sodium alginate and carboxymethyl cellulose edible coating	Ziziphora essential oil	Fresh pork	Ruan et al. [153]

## Antimicrobials

Meat and meat products being primary causes of foodborne diseases are also prone to spoilage during storage as with all proteinous foods [34]. EOs have been shown to possess antibacterial and antifungal against several microorganisms associated with meat, including Gram-negative and Gram-positive bacteria [94].

Regarding the meat and meat products, EOs from oregano [162], rosemary, thyme [189], clove [167], balm, ginger, basilica, coriander, marjoram, and basil have shown a greater potential to be used as an antimicrobial agent [19, 57, 68, 169]. Essential oils rich in phenolic compounds like clove, oregano, rosemary, thyme, sage and vanillin oils be the most

effective [78]. Cutter [42] demonstrated that antimicrobial agents, when incorporated into the packaging films, could be effective for reducing levels of foodborne organisms.

Oregano essential oil has been the most commonly reported, including a 1.5% extract (v/v), successfully used to reduce total viable count by 2 log CFU/g of cold-smoked sardine [98], whereas at 1.9% it achieved *L. monocytogenes* population reduction by 2.4 log CFU/g after 28 days, at 4 °C in wrapped cold-smoked salmon [105]. Combined Oregano essential oil and thyme extract, was incorporated into a film placed on top and bottom of fresh ground beef patties reducing *Pseudomonas* and coliforms count [21], whereas mixed with pimento essential oil, the films covering beef muscle slices reduced to 1 log of *E. coli* O157:H7

**Table 2** Essential oil incorporated edible film for antioxidative property

Film	Essential oil	Substrate	References
Milk protein-based edible films	1.0% (w/v) oregano, 1.0% (w/v) pimento, or 1.0% oregano-pimento (1:1) essential oils	Whole beef muscle	Oussalah et al. [132]
Gelatin-based functional edible films	Oregano ( <i>Origanum vulgare</i> ) or Rosemary ( <i>Rosmarinus officinalis</i> )	Cold-smoked sardine ( <i>Sardina pilchardus</i> )	Gómez-Estaca et al. [65]
Chitosan film	Clove ( <i>Syzygium aromaticum</i> L.), fennel ( <i>Foeniculum vulgare</i> Miller), cypress ( <i>Cupressus sempervirens</i> L.), lavender ( <i>Lavandula angustifolia</i> ), thyme ( <i>Thymus vulgaris</i> L.), herb-of-the-cross ( <i>Verbena officinalis</i> L.), pine ( <i>Pinus sylvestris</i> ) and rosemary ( <i>Rosmarinus officinalis</i> )	Fish	Gómez-Estaca et al. [64]
<i>Plantago major</i> seed mucilage	<i>Anethum graveolens</i> essential oil	Beef	Behbahani et al. [22]
Gelatin composite films	Nanorods/clove essential oil	Shrimp packaging	Ejaz et al. [54]
Whey protein active coatings	<i>Origanum virens</i> essential oils	Processed meat	Catarino et al. [35]
Chitosan film	Anise ( <i>Pimpinella anisum</i> L.) essential oil	Chicken burger	Mahdavi et al. [119]
Chitosan edible films	<i>Thymus moroderi</i> and <i>Thymus piperella</i> essential oil	Cooked cured ham	Ruiz-Navajas et al. [154]
Alginate-based edible coating	Rosemary and oregano essential oils	Beef	Vital et al. [179]
Quince seed mucilage edible films	Oregano or thyme essential oil	Rainbow trout fillets	Jouki et al. [92]
Silver carp ( <i>Hypophthalmichthys molitrix</i> ) skin gelatin-chitosan	Oregano essential oil	Fish	Wu et al. [185]
Pomegranate juice dipping and chitosan coating	<i>Zataria multiflora</i> Boiss essential oil	Chicken meat	Bazargani-Gilani et al. [20]
Carboxymethyl cellulose edible coating	<i>Zataria multiflora</i> essential oil	Rainbow trout meat	Raeisi et al. [150]
Soy edible films	Oregano or thyme essential oils	Ground beef patties	Kodal Coşkun et al. [104]
Chitosan-gelatin film	<i>Ziziphora clinopodioid</i> essential oil	Minced trout fillet	Kakaei and Shahbazi [93]
Chitosan nanoparticles	Cinnamon essential oil	Chilled pork	Hu et al. [83]
Chitosan coatings	<i>Zataria multiflora</i> Boiss oil	Chicken breast meat	Mehdizadeh and Langroodi [122]
Pectin-fish gelatin films	Olive	Beef meat	Bermúdez-Oria et al. [24]
Chicken meat protein coatings	Thyme or clove essential oil	Beef sucuks	Saricaoglu and Turhan [158]

after 7 days of storage at 4 °C [66]. Grapefruit seed extract (GSE) incorporated into AEFC was found to inhibit *E. coli* O157:H7 and *L. monocytogenes* from pork loins [147], bacon [167] (Table 1).

## Antioxidant

Oxygen is responsible for many degradation processes in foods such as lipid oxidation, micro-organism growth, enzymatic browning and vitamin loss [14]. The oxidation of fat results in off-flavor, off-color and nutrient loss [79]. Essential oils from oregano [189], sage rosemary, thyme, and pimento are reported to possess antioxidant properties comparable to or greater than BHA or butylated hydroxy-toluene (BHT) [23, 82]. Oussalah et al. [132] reported the antioxidant properties of milk protein-based edible films

containing oregano, pimiento and oregano-pimiento mix. Pimiento-containing films provided the highest antioxidant activity on beef muscle slices; oregano-based films were also able to inhibit lipid oxidation in beef muscle samples.

Fortifying films with bioactive ingredients such as citrus-based essential oils [176], green tea extract [63], butylated-hydroxy-toluene (BHT) and a-tocopherol [91]. Seaweed extracts, being rich in phycocolloids, phenolics, and other antioxidative compounds, are a very good source for the fortification of biopolymer-based films (Table 2).

## Conclusion

The use of edible films and coatings represents a stimulating route for creating new food packaging materials. Contrasting edible films have been developed by researchers for meat packaging over the years. However, some challenges like economy, applicability and least sensorial alteration of meat and meat products still remains. All of these shortcomings lead to flawed liaisoning between the researchers and industry emanating limited commercial acceptance. The frequent benefits of technique to food processors and consumers by effective edible film packaging must be justified and further research in this field is realized.

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