DOI: https://doi.org/10.21323/2414-438X-2024-9-2-169-179
Received 06.05.2024
Accepted in revised 22.06.2024
Accepted for publication 25.06.2024

Available online at https://www.meatjournal.ru/jour
Review article
Open Access

BIODEGRADABLE MEAT PACKAGING: MICROBIAL SAFETY AND CONTROL OF ENVIRONMENTAL POLLUTION

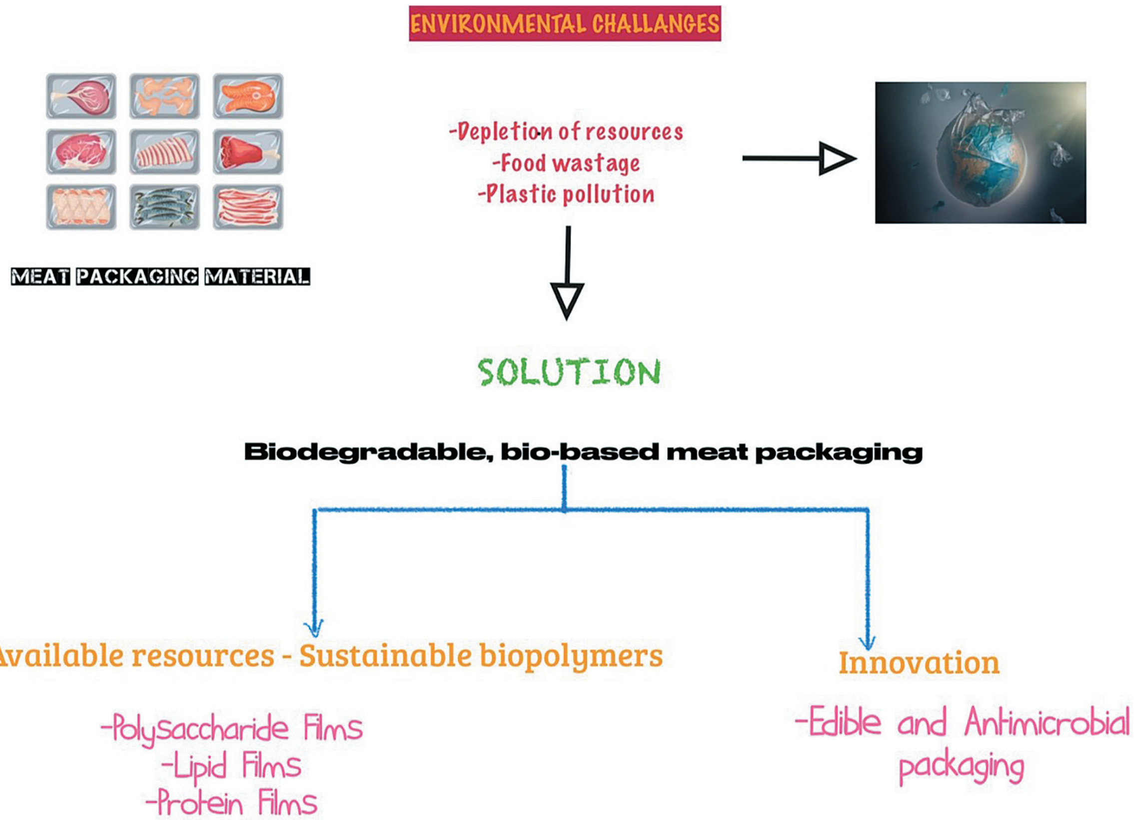
Kanza Saeed[1],* Zaryab Ali[2]
[1] Khwaja Fareed University of Engineering and Information Technology, Rahim Yar Khan, Pakistan
[2] Charoen Pokphand Pakistan Pvt. Ltd

Keywords: *meat and meat products, antimicrobial, biodegradable, edible film*

Abstract
Plastic fragments from packaging material not only pollute the environment but also contaminate food material, causing detrimental health effects. The ultimate solution to this "white" pollution is biodegradable food packaging material. These films can be produced using proteins, polysaccharide and lipid-based materials and can enhance the shelf life of perishable commodities like meat and meat products by incorporating the natural antioxidant and microbial compound in packaging matrix, like essential oils. Essential oils of the aromatic plants due to their diverse phenolic profile possess strong antimicrobial and antioxidant potential, they open new doors of research to develop less hazardous food preservatives and drugs. These films and coatings improve nutritional and sensory attributes of packaged food. These films not only improve food quality but also overcome the burden of environmental pollution.

For citation: Saeed, K., Ali, Z. (2024). Biodegradable meat packaging: Microbial safety and control for environmental pollution. *Theory and Practice of Meat Processing,* 9(2), 169–179. https://doi.org/10.21323/2414-438X-2024-9-2-169-179

Graphical Abstract:



Introduction

Nowadays, with increasing awareness regarding the harmful impact of synthetic material both on health and environment, people started focusing their attention on usage of the natural and highly nutritious food with least synthetics involved [1]. However, there are certain perishable commodities which will deteriorate without use of chemical additives. One of the most spoilage prone food category is meat and meat products; as they have high percentage of fat content particularly unsaturated fatty acids.

Lipid oxidation is the major type of quality deteriorative change that occur in meat and meat products [2]. During lipid oxidation chemical reactions results in color and textural changes, off-odor, off-flavor, discoloration caused due to myoglobin oxidation occur, which greatly impacting consumer acceptance and choice [3]. In addition to organoleptic changes, certain toxic compounds like aldehyde and ketones are formed during lipid oxidation and some valuable nutrients are lost [4].

Deteriorative losses of meat and meat products cause immense economic losses in global industry i. e. up to 40% of total meat production [5]. In order to control these deteriorative losses, we need to explore and understand the chemical interactions in the process of deteriorative changes. Selection and designing of packing material crucial in terms of material and format to reduce quality losses. One of the most commonly adapted technique to prevent lipid oxidation is by reducing oxygen levels in packaging either by creating vacuum or by adding other gases like nitrogen [6]. Residual oxygen even at low concentration (0.05%) can still cause pigmentation and lipid oxidation [7]. In case of fresh red meat, it is usually packed in oxygen rich environment in order to maintain it pinkish red color due to oxymyoglobin but this often result in to undesirable lipid oxidative changes [8]. In order to deal with the abovementioned problems food industries and scientific community have been working to create new packaging systems that will extend meat shelf life and retain its desired quality characteristics [9].

Packaging system in food processing occupy prominent position, having dispensable use in distribution as well as commercialization in the market [10]. Food packaging is greatly influenced by emerging novel technologies and innovative materials like active packaging [11]. The increasing consumer demand of natural, unprocessed and chemical free food, can be fulfilled through sustainable packaging system [12]. The central idea behind these innovative technologies involves incorporation of active compounds in packaging designs like antioxidant packaging contains antioxidants either natural or synthetic with the purpose of lipid oxidation prevention, which will eliminate the need of adding antioxidants during meat processing [13]. The objective of the current review is to study the impact of biodegrade packaging material with plant extracts and essential oils on safety profile of highly perishable meat and meat products.

Objects and methods

Analysing the research of national and international scientist from around the globe on effect of synthetic meat packaging material on environmental pollution and exploration of safe and sustainable, natural biodegradeable packagaing materials was the prime objective of the study. Data collection was based on most recent advances and findings regarding biodegradable meat packing available on electronic sources like google scholar, ScienceDirect, Elsevier, Wiley, PubMed and eLibrary. English keywords like meat and meat products, antimicrobial, biodegradable, edible film were used. Citation links were used to explore thematically similar articles. While, the data that is irrelevant to the topic, uninformative, duplicated or from non-peer-reviewed sources has been excluded from the study.

Synthetic material used in meat packaging

Different packaging materials are used for packing of meat products: flexible plastic films as well as combination of flexible plastic packing material, carton boards, rigid containers are also used [14]. Mechanical strength provided by polymeric material is a necessity for proper protection of packaged food; particularly in the final application where packages are subjected to low storage and transportation temperature [15]. For packing of meat, prime wraps are usually the multilayer films made from polyvinylidene chloride (PVDC) polymers [16]. Facilitating consumption into the distant locations, meat packaging is one of the most complicated domains into food packaging, assigned for proper protection of goods, combination of list of materials and processes are developed [15]. In packaging structures, different polymer families are used which are polyethylene (PE), polypropylene (PP), polyvinylidene chloride (PVDC) and different copolymers [17].

Various features can be aggregated into few elements with the objective of protection are the following:

- Sealing for proper hermeticity;
- For food protection, providing barrier to keep the internal environment safe;
- To evade failures due to internal punctures caused by mechanical impact from cured and bone meat pieces [15].

By modern processes such as co-extrusion, different elements are assorted into united mixtures [18]. To achieve the objective, all packaging materials together, adhesive lamination or co-extrusion coatings are used. Co-extrusions coatings are being used for the few recent years because it simplifies production process of packaging films, that complies to the performance requirements by direct extrusion. The responsibility of packaging designers is to reduce the packaging impact on broadened product life, minimizing footprint from packaging as well as product and providing proper information of product life, materials usage, reusing, disposing and recycling within the extended process in order to select the appropriate process [19].

Environmental impact of synthetic material used in food packaging

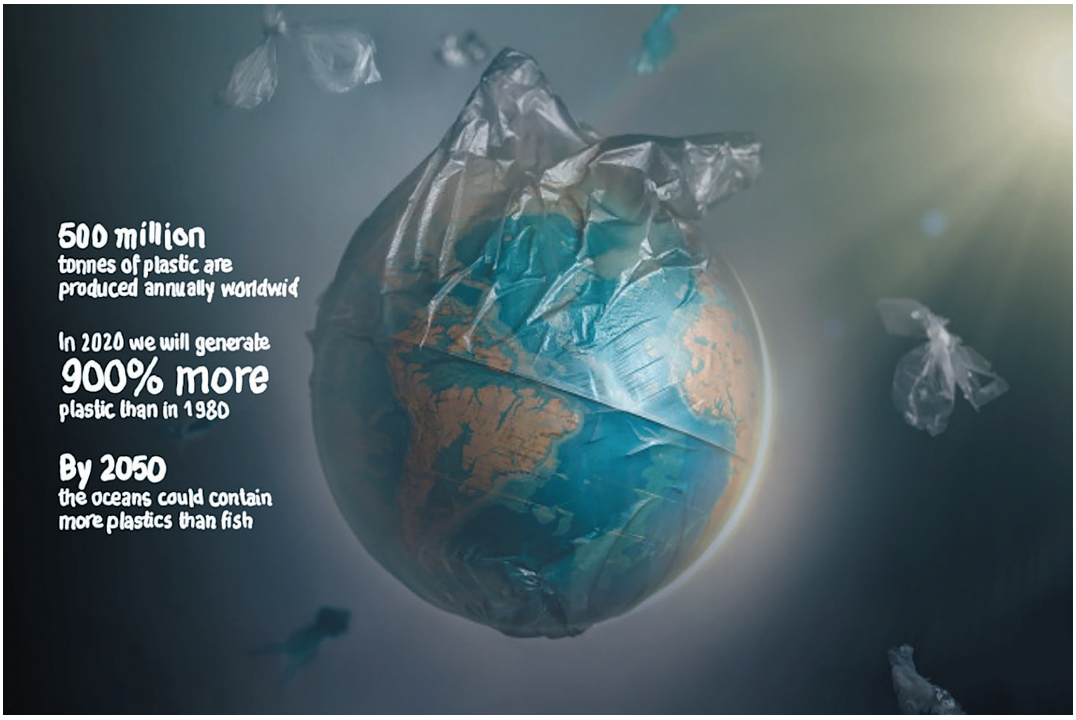
The need to provide ordinary plastic materials has been a subject of paramount interest, considering their unsustainable nature and maintenance of sheen appearance. In the modern culture, these materials are found all over. They are among the top used materials primarily because of their principle attributes: they are adaptable, simple to measure and control, naturally non-reactive, and can be acquired at low expenses [20].

All of the abovementioned properties have strongly promoted using of plastics for various applications, from cell phones, 3D printing to the food business [21,22]. These days, plastic pollution is found all over the globe, including soil, seas, drinking water resources, in living bodies being found in residual form [23]. The deposition of plastics in environment will increase by twofold over the course of the following 20 years, outperforming to a disturbing degree of the current waste administration and recycling capacities. It appears to be that plastic contamination has become the greatest ecological concern of present days. To deal with the problem, various organizations are joining their efforts with the assistance of non-administrative associations and common society, through various projects that address the current issue, provide assistance for accessing the circumstances and develop remedial measures [24]. Indeed, in 2018, the European Union, reclamation programs planned to create systems to reduce the utilization of plastics in order to conserve the climate [24]. There are two issues that should be addressed; the first one is the monetary evaluation: it is estimated that only 5% of the plastic materials is kept up in the economy, the rest being lost after the primary use, which brings about yearly financial losses of 70–105 million Euros; and the second one: due to their diminished quality over excessively significant period of time that it take, non-reused plastic requires a long time to decay, unlike other materials like glass, paper, or metals. In this way, loads of non-degradable materials came into existence as a savior of environment. Among all the plastic pollution cases, the most disturbing results are gigantic sea depositions ranging from 5 to 13 million tons/year [25].

It is assessed that burning plastics produces around 400 million tons of additional CO_2 each year. The methodology adapted by European pioneers revolves around the concept of bioeconomy, with ultimate objective of protecting the planet and its residents from the havocs of non-degradable plastics. As indicated by these plans, by 2030, packaging material used in European markets will be recyclable and the utilization of plastics packaging will be diminished. Various organization like European bioplastics are focused on decreasing plastic waste, preventing mass stockpiling, and putting resources into nature restoration, and developing new materials [26]. Reevaluating and improving this framework require participation and due endeavors from all players of the field, from plastic producers to recyclers, retailers and its buyers. Without the dynamic contribution of every prime-level entity, a definitive objective cannot be accomplished i. e. to create revolutionized plastic economy. The plan is to create plastic that can be reused, this activity will relieve environmental constrains because of plastics and its unfavorable effects on individuals and the overall environment. Figure 1 shows the environmental impact of synthetic material used in food packaging [27].

Biodegradable and edible packaging

The introduction of entirely biodegradable and edible materials derived from bio-based polymers to the environment can be a real and authentic solution for eradication of pollution. The polymeric materials derived from renewable raw materials are known as bio-based polymers [28]. Some noteworthy properties of these packaging material includes its biodegradability, ability to be recycled, having low cost of development, naturally abundancy, non-toxicity and biocompatibility, these are the reasons behind their possible extensive applications in order to generate novel materials [29]. In 2011, production of bio-based polymers



https://www.podbean.com/ew/pb-45hcm-15d7f71

Figure 1. Artistic representation of the environmental impact of synthetic material used in food packaging

was around 3.2 billion tonnes and it reach to 12 billion by 2020 [30]. Biomass can be used to generate bio-based polymers in the food industry, which can be either synthesized by microorganisms or by bio-derivative monomers. Bio-based polymers used in the food industry can be obtained from bio-monomers derived from biomass, produced by microorganisms. While choosing these polymers, the requirements of the coating material which has to fulfilled is taken into keen consideration. The consumers' interest in minimally processed foods has been increased by application these coatings or films [31].

Even though biodegradable packaging seems to be a cut-the-edge technological solution, there are historic evidences of its application since 16th century [32]. Covering the meat pieces or carcasses in lipid-based coatings have been used since prehistoric times [33]. Emulsion derived from waxes and oils in water is the most used and common method of applying edible coatings to the meat. In case of food material, it is sprayed directly on to the surface, which helps in improving its sensory properties like glossiness, appearance, color, fineness [34]. These coatings also control the browning process and loss of water from the tissue cells. Numerous polysaccharide-based coatings and films are used to enhance the quality and storage of meat including pectin, alginates, cellulose and starch derivatives etc [35].

Edible packaging is defined as packaging technique in which the packing material i. e., films, coatings etc. are a part of that product and is consumed together with the food [36]. Films are independent materials that cover the surface of food materials while coatings are applied to the surface directly. Edible properties of these coatings can only be acceptable for food applications only if the ingredients used in the packing materials are food graded and the methods of their processing and obtaining are approved by the food safety regulating authorities. Product quality and freshness of the food material depends largely upon the correct selection of materials and the packaging technologies used [37].

Even though the edible films and coatings can be regarded as part of food, but it cannot be considered as the finished product. Edible coatings are not classified within food class as they do not provide the calculated nutritional value [38]. Material used for generation of edible films and coatings should have properties such as (a) decreased permeability (b) water tightness (c) strong barrier properties and mechanical efficiency (d) high sensory quality [39] (e) ability of endure low pressure processing conditions (f) non-toxic and non-hazardous for consumer's health [40] (g) decreased viscosity (h) non-polluting (i) physiochemical, microbiological and biochemical stability (j) producible through low cost and simple development technology (k) easily emulsifiable and non-sticky (l) should not produce excessive CO_2 (m) made of cheap plant materials (n) does not interfere with the food quality (o) has no taste or smell which is detectable at the time of consumption (p) mildly transparent but not like glass (q) have decreased viscosity. Refer to Figure 2 as it enlists the functions of food packaging material [41].

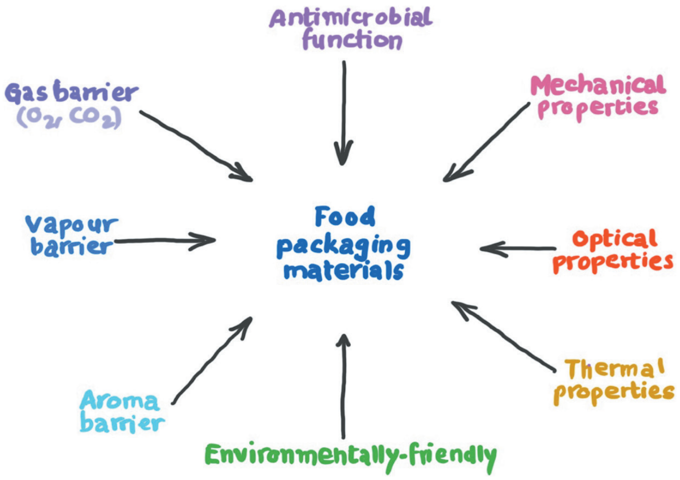


Figure 2. List of the functions of food packaging material

Despite of the edible packaging with properties similar to the plastics, on the basis of functional performance the edible food packaging competes really well with the plastics, especially due to strong barrier properties against loss of vapors and solutions, but usage of these material requires some additional packaging support to sustain hygiene and handling operations. The efficiency of bio-based polymeric coatings and films can be augmented by additions of natural substances which improve the physicochemical, mechanical and microbiological characteristics of the packaging material [42]. Due to consumers' demand for natural products this trend is flourishing. To fulfil this consumer requirement; dyes, antioxidants, essential oils and flavoring compounds are being added to the food packaging [11]. Research trials are also being conducted for development of smart nano-material packaging which have features far more superior then the conventional films [43].

Renewable source derived polymeric materials are regarded as biopolymers. These materials have numerous food applications. These biopolymers have three major classifications on the basis of their origin and method of production. First, biomass-derived polymers. For example, protein-based polymers of casein and gluten, polysaccharide-based polymers of chitin, cellulose, chitosan and starch. Figure 3 shows the biopolymers which can be used as meat packaging raw material. Second category includes renewable monomeric biomass; polymers derived from classical chemical synthesis e. g., polylactic acid, a lactic acid monomer made via bio-polyester polymerization. The third category includes polymers produced by microorganisms and genetically modified bacteria e. g., polyhydroxy alkenoates [6].

Commonly in retail trade the plastic trays, used in order to pack fresh poultry, mutton, beef or fish, are destroyed during storage due to dripping of juices, that makes the packaging unappealing to the consumer [44]. Bio-based meat coating have ability to retain natural meat juices which help to reduce dripping, and eliminate the need of absorbent pads beneath meat cuts in the trays, thus, improving

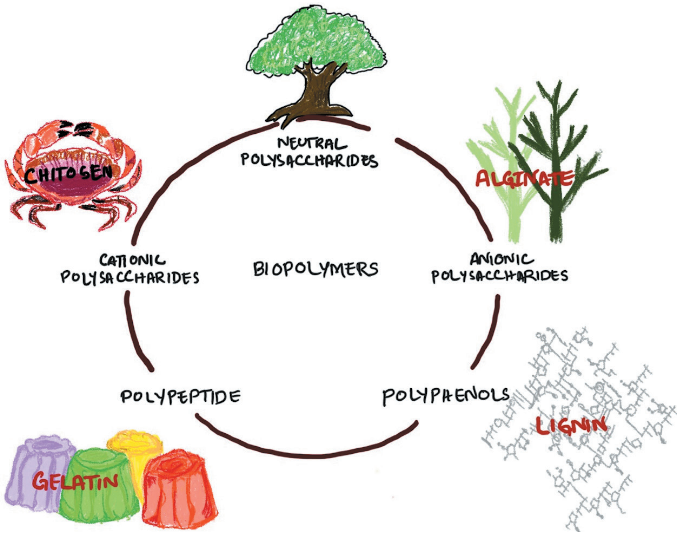


Figure 3. Biopolymers which can be used as the raw materials for meat packaging

the product presentation [45]. Bio-based coatings also prevent meat browning caused by myoglobin oxidation, prevent rancidity due to low oxygen permeability, reduce deteriorative activity of proteolytic enzymes, reduce microbial load in the packaged meat; these packaging materials also restrict loss of volatile flavors, and prevent absorbtion of foreign odors by poultry meat and seafood [6]. These bio-based packaging contains natural antimicrobials and antioxidant compounds, thus can be used for direct application or covering onto the meat surface, resulting in color retention, delayed rancidity and decreased microbial load [46]. These coatings if applied prior to procedures like battering, breading or frying, preserve product nutritional profile by restricting oil uptake during cooking procedure [47].

Biodegradable meat packaging materials

Polysaccharide films in meat packaging

The polysaccharide derived films are made from materials like cellulose, starch, carrageenan, pectin, ether, alginate, chitosan and etc. [35]. The peculiar properties of these materials include compactness, rigidity, tackiness, viscosity, thickening and structure in aggregate forming the capability necessary to generate packaging films. Gas permeability of polysaccharide film is higher in comparison to lipids films which create an anaerobic environment within food package; making polysaccharide film is more suitable for creating modified atmosphere-permeable packaging to enhance product shelf life without creating anaerobic conditions. These films also prevent rancidity, dehydration and surface browning issues of the packaged food. The polymeric network of polysaccharide films, restrict gaseous exchange across the film but being hydrophilic in nature this material is a weak barrier against water vapors [35]. In Japan for years these polysaccharide films have been used to wrap the meat, when it is subjected to steam smoke. During processing these films become integrated to the meat surface, resulting in improved texture, moisture retention, better structural characteristics [48].

Seaweed derived alginates have film forming properties; these films are usually created in combination with cations like Ca, Mg, Fe or Al to improve gelling characteristics. According to the findings of a study conducted by Gutt and Amariei [37] sodium alginate base creates eco-friendly meat packing material, and reduces the use of plastic material. During this study it was found that alginates, in particular sodium alginate films, are tear-resistant, flexible, glossy, tasteless, odorless, feature low oxygen permeability thus effectively prevent color and taste degradation in meat.

Starch is composed by complex network of amylose and amylopectin, has physical properties comparable to synthetic plastics but is tasteless, colorless, odorless, non-toxic biodegradable, it exhibits strong oxygen barrier and has semi-permeability for carbon dioxide [49]. These films not only protect meat quality during storage but also become part of it during cooking. These films control microbial growth by lowering water activity, reducing drip losses and ensure moisture retention [50]. According to a study conducted by Zhao et al. [51] starch films created by combination of chitosan and caravol have been found effective in controlling *Listeria monocytogens* and ham meat microbiota.

Mixture of various polysaccharides like carrageenan, in combination with bioactive compounds like gallic and ascorbic acid, improve microbial stability of boneless meat. Farhan and Hani [52] created Kappa-carrageenan active edible biofilms to prevent oxidation and to retain color of packaged chicken breast. The study proved that bio-based film improved antioxidant activity and controlled microbial load on chicken breast during 7 days storage study. Cellulose, non-digestible fiber, is resistant to fats and oils permeation, it is flexible and water soluble. Cellulose-based films exhibit characteristics like mechanical strength, serve as oxygen- and oil-resistant barrier, making it perfect to store boneless meat. Pirsa and Shamu [53] created an active packaging made from cellulose-polypyrrole-ZnO to improve the shelf life of chicken thigh meat and found that this film reduced the microbial load of stored meat, increased its shelf life and improved rheological stability of chicken thigh because of enhanced antimicrobial and antioxidant activity.

Pectin, a plant-derived polysaccharide, has stable physical structure but it is poor moisture barrier. But there are numerous studies about effective pectinate gel packaging like Xiong et al. [54] prepared edible pectin coating containing nano-emulsion of oregano oil and resveratrol for preservation of pork loin, and found effective results at refrigeration temperature for 15 days. Similarly, Sani et al. [55], prepared potato starch, apple peel film with ZnO_2 nanoparticles and with microencapsulation containing *Zataria multiflora* essential oil for quail meat packaging and found that packaging film enhanced meat shelf life and retained its physiochemical properties. Agar is a seaweed-derived polysaccharide, having strong gel forming characteristics, it is also used for meat packaging. Chitosan, a biodegradable polymer derived from arthropod exoskeletal compound chitin, demonstrate antimicrobial and antioxidant properties along with considerable tensile strength [56]. Souza et al. [57] created ecofriendly ZnO-chitosan packaging films for fresh poultry meat packaging and demonstrated its strong antimicrobial characteristics. Incorporation of nanoparticles enhanced antioxidant characteristics of the packaging film. Similarly, Arkoun et al. [58], created activated chitosan-based nanofiber meat packaging and tested it against *Salmonella enterica serovar Typhimurium*, *Staphylococcus aureus*, *Escherichia coli* and *Listeria innocua* strains that are blamed in quality deterioration of boneless meat, and found that film prevented meat contamination and extended meat self-life up to 1 week.

Lipid films in meat packaging

Fats in foods have been used as oxygen and moisture barrier in order to prevent shrinkage of food material. Lipid films, particularly wax-based have flexibility, feature better coating characteristics and improve cooking procedures by preventing sticking to utensils. These coatings prevent food moisture loss, thus retaining the meat flavors. Edible wax coating easily withstands rough market handling, lessen surface dehydration and preserve meat color [59]. Song et al. [34] incorporated sunflower oil into edible coating for pork meat hamburger, making it possible to control oxygen levels as well as modulating water vapors, thus preventing undesirable deteriorative reactions in meat. Despite the above-mentioned benefits at higher storage temperatures lipid-based films exhibit lower gas permeability particularly for ethylene, oxygen and carbon dioxide, creating anaerobic conditions leading to food safety issues. These films also have poor sticking properties as the hydrophilic surfaces lack structural integrity and are prone to oxidation, flaking, cracking, retain off flavors and have bitter aftertaste [60].

Protein films in meat packaging

Casein, gelatin/collagen, whey protein, fibrinogen, wheat gluten, corn zein, egg albumen and soy protein have been processed to produce biodegradable edible films [61]. These protein-based films cannot resist water diffusion but have ability to adhere to hydrophilic surfaces and provide barriers for oxygen and carbon dioxide [62]. Commercially milk proteins, casein and whey have been used in the manufacturing of these films. These proteins are desirable for films formation not only because of their packaging properties (excellent mechanical strenght, barrier properties, water solubility, emulsification properties) but also because of their nutritional value. For years research has been conducted on milk protein films for packaging of fruits, vegetables and other dairy foods and boneless meat [63].

Catarino et al. [64] prepared active whey protein coating enhanced with *Origanum virens* essential oil to increase the shelf life of processed meat. The coated sample — Portuguese sausage — was regularly monitored for 4 months long for total microbial load and physicochemical characteristics, and found an approximate 20 days extension in its shelf life. During storage the study considered color retention, the reduced lipid peroxidation was also observed. Similarly, Furcellaran and whey protein isolates were used to prepare biodegradable packaging material with *Borago officinalis* extracts to preserve ham. A 21-day storage study was conducted and the samples were tested every 7 day and found satisfactory results of oxidation product build-up, microbiological load and organoleptic characteristics [65].

Sanches et al. [66] prepared starch-based active packaging containing sweet whey and red cabbage extract for packaging of ground beef and found that films have strong antioxidant potential, good machine-processing strength, low permeability for water vapors, making it a suitable material for packaging of meat and meat products like ground beef. This film improves the shelf life due to presence of anthocyanins. Song et al. [34] utilized whey isolates-coated multi-layer films as a gas barrier in order to minimize qualitative changes in frozen and marinated meat loaves and the results demonstrated that these films preserve physicochemical and organoleptic characteristics of meat loaves during 6-month storage study, proving the potential of whey isolate-coated film for commercial application.

Edible meat packaging (films and coatings)

An edible coating/film is any material with an average thickness of less than 0.3 mm and which can be produced from combination of biopolymers and various additives dispersed in aqueous media. In literature authors use the terms of edible coating and edible films interchangeably; however, some others consider that coating and films have distinction in terms of the techniques used to incorporate them into the food product. The edible coating is formed directly on the food, whereas the edible film is as first prepared separately and then applied onto the product [67].

Microbial growth in meat, fish and derived products result in the quality decay, which can be prevented by adding or enhancing the antimicrobial activity of the packaging films and coatings, making it an interesting strategy to extend the food shelf life [50]. Essential oils, ethanolic, aqueous extracts of plants provide a diverse range of natural preservatives [68]. The key reason of encouraging the application of these natural substances in food preservation is linked to their compliance with desired characteristics of biodegradability, bioactivity and edibility of these biobased edible film and coatings.

Films with incorporated active components like herb extracts are rich in phenolic compounds and terpenoids that prevent growth and propagation of microbial flora in meat products. Essential oils contain bioactive compounds like carvacrol, thymol, menthol, eugenol and etc. Isopropyl phenols like carvacrol are hydrophobic compound with capability to accumulate in the microbial cell membrane, where they induce conformational modification, that ultimately leads to microbial cell death. Monoterpenes like thymol and menthol cause lipid fraction perturbation in microbial cell membrane, re-arrange its permeability thus resulting in leakage of microbial cell content. Similarly, oregano essential oil transmutes microbial membrane permeability thus resulting in leakage of essential nutrients like phosphates, potassium and protons. These bioactive agents also upgrade film barrier properties due to chemical interactions between film matrix and polyphenolic compounds [69]. Figure 4 explains the possible mechanisms of antimicrobial activity of bioactive compounds.

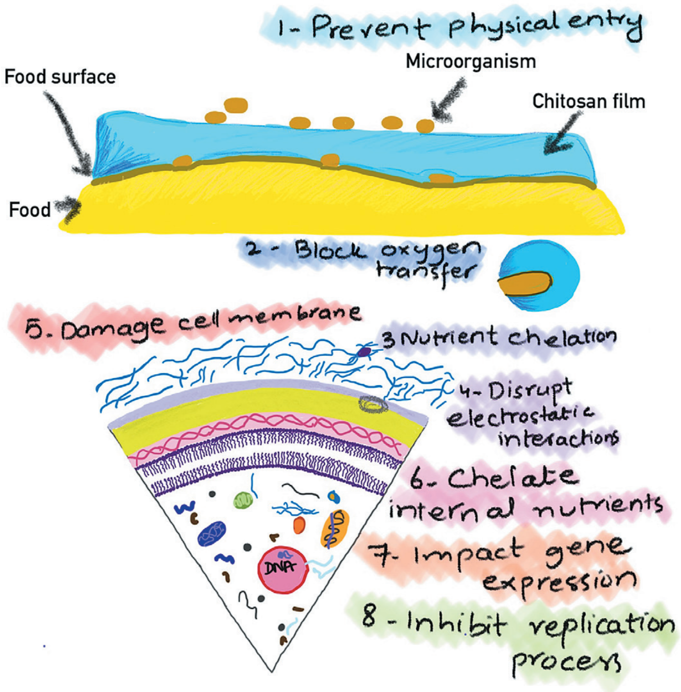


Figure 4. Visual explanation of the possible mechanisms of antimicrobial activity in bioactive compounds

Edible coating made of immiscible biopolymer composite increases shelf life fresh meat cuts by reducing drip losses, lipid oxidation, metmyoglobin formation and retains natural volatile meat flavors [48]. Gheorghita et al. [70] developed edible material film using stevia, sodium alginate and agar for study of storage of ham slices and cheese for 5 months at refrigerated conditions and after the expiry of this period evaluated color, waters activity index and peroxide index. The results made it evident that the film does not support the growth of existing meat and cheese microflora proving that this biopolymer can be a promising substitute for unsuitable commercial plastics.

Giatrakou et al. [71] conducted a study on antimicrobial impact of chitosan coating in a 4 weeks storage study on pastrami, and reported one log of CFU/g reduction in aerobic plate count. Fattahian et al. [72] prepared edible chitosan coating to create modified atmospheric packaging for meat. *Caminum cyminum* essential oil was incorporated in the film because of its antimicrobial and antioxidant properties. Bazargani-Gilani et al. [73] reported another interesting outcome of chitosan film with *Zataria multiflora* essential oil. This experiment was run on chicken breast, kept at 4 °C for a period of 20 days, revealed a significant inhibition of both total viable and psychotropic microflora. Another trial on microbial growth of selected species (*Pseudomonas spp., Enterobacteriacea*, yeasts and molds) in untreated meat, packed in chitosan coating with grape seed extract, exhibited significant reduction of microbial growth in chicken breast meat [74]. Incorporation of oleoresin extracted from kaffir lime leaves into cassava starch coating improved the microbial stability of beef samples during storage [75]. The study indicated a remarkable reduction in the growth of microorganism in 2 weeks storage study. Similar outcomes were reported by Dharmalingam et al. [76] for beef fillets packaged in cassava starch coating enhanced with clove and cinnamon essential oils.

There are numerous studies that highlight meat and fish preservation against target microorganisms primarily responsible for meat spoilage (*Escherichia coli, Listeria monocytogenes* and *Staphylococcus aureus*). For instance, in one study there was tested the antimicrobial activity of thyme and oregano essential oil in soy protein coating at a concentration of 3% for its capability to inhibit the growth of *Escherichia coli, Listeria monocytogenes* and *Staphylococcus aureus* in refrigerated beef fillets kept for two weeks. The researchers monitored the samples periodically and found that the growth of all microorganisms was drastically inhibited throughout the storage period [77]. In another study of the wrapped flounder fillets, the protein hydrolysate of agar film with incorporated clove essential oil inhibited the growth of food spoiling microorganisms under refrigerated storage conditions, thus, improving the shelf life from 10 to 15 days [78].

Due to high protein content beef is more prone to microbial and enzymatic spoilage. *Pseudomonas* spp., lactic acid bacteria, *Enterobacteriaceae*, yeasts and molds are the major spoilage causing agent. In order to prevent the oxidative reactions and microbial growth during a study of 20 days of storage, chitosan edible film enhanced with *Zataria multiflora Boiss* oil and sumac extract was prepared to maintain a modified atmosphere condition for beef packaging and demonstrated encouraging results proving its suitability as meat edible packaging for commercial applications [79].

Dalvandi et al. [80] created an edible poultry packaging by dipping meat into solution of carboxy methyl cellulose with added extracts of turmeric and black pepper seeds, vacuum-packed the meat and placed it under refrigerated conditions for a storage study, and found that this edible packaging can considerably enhance the durability of breast fillets of chicken. In another study, edible composite film of gelatin enriched with polyphenolic nano-emulsions was used to create packaging for chicken meat and showed that water stability and moisture of the film reduced with increasing nano-emulsion concentration. This film has strong antioxidant potential due to curcumin extracts in nano-emulsions, which also prevented growth of *Salmonella typhimurium* and *Escherichia coli* in packaged meat, thus, extending the shelf life of meat up to 17 days [81]. Interestingly, in another study the antimicrobial characteristics of both sodium alginate-carboxymethylcellulose film and coating infused with *Ziziphora clinopodioides* essential oil, apple peel extract and zinc oxide nanoparticles were prepared, and the results of meat storage study exhibited the considerable improvement in preservation of meat quality [82].

Conclusion

Current alarming levels of environmental pollution are driving the researcher to develop the alternatives for non-biodegradable packaging materials that naturally disintegrate without causing damage to the environment. These packaging materials are edible and are derived from renewable and sustainable agricultural products. The edible films enhanced with natural plant extracts have antimicrobial and antioxidant properties that prolongs the shelf life and safety of foods by preventing the growth of pathogenic and spoiling microorganisms. In meat industry, microorganisms may cause severe food safety issues linked with health problems, such as foodborne diseases. However, development of the new bio-based films and coatings is urgently required to respond to the problems of environmental pollution and provision of safe food.

REFERENCE

1. Saraiva, A., Carrascosa, C., Raheem, D., Ramos, F., Raposo, A. (2020). Natural sweeteners: The relevance of food naturalness for consumers, food security aspects, sustainability and health impacts. *International Journal of Environmental Research and Public Health*, 17(17), Article 6285. https://doi.org/10.3390%2Fijerph17176285
2. Li, F., Zhong, Q., Kong, B., Wang, B., Pan, N., Xia, X. (2020). Deterioration in quality of quick-frozen pork patties induced by changes in protein structure and lipid and protein oxidation during frozen storage. *Food Research International*, 133, Article 109142. https://doi.org/10.1016/j.foodres.2020.109142
3. Goretska, M. (2023). The effect of recommended consumer thawing methods on the internal cooked color of ground beef patties. Master's thesis, Oklahoma State University, 2023.
4. Grebenteuch, S., Kanzler, C., Klaußnitzer, S., Kroh, L. W., Rohn, S. (2021). The formation of methyl ketones during lipid oxidation at elevated temperatures. *Molecules*, 26(4), Article 1104. https://doi.org/10.3390%2Fmolecules26041104
5. Karwowska, M., Łaba, S., Szczepański, K. (2021). Food loss and waste in meat sector — why the consumption stage generates the most losses? *Sustainability*, 13(11), Article 6227. https://doi.org/10.3390/su13116227
6. Cenci-Goga, B. T., Iulietto, M. F., Sechi, P., Borgogni, E., Karama, M., Grispoldi, L. (2020). New trends in meat packaging. *Microbiology Research*, 11(2), 56–67. https://doi.org/10.3390/microbiolres11020010
7. Andrade, B. F., Guimarães, A. S., do Carmo, L. R., Tanaka, M. S., Fontes, P. R., Ramos, A. de L. S. et al. (2024). S-nitrosothiols as nitrite alternatives: Effects on residual nitrite, lipid oxidation, volatile profile, and cured color of restructured cooked ham. *Meat Science*, 209, Article 109397. https://doi.org/10.1016/j.meatsci.2023.109397
8. Faustman, C., Suman, S. P., Ramanathan, R. (2023). The eating quality of meat: I Color. Chapter in a book: Lawrie's Meat Science. Woodhead Publishing, 2023. https://doi.org/10.1016/B978-0-323-85408-5.00023-6
9. Soro, A. B., Noore, S., Hannon, S., Whyte, P., Bolton, D. J., O'Donnell, C. et al. (2021). Current sustainable solutions for extending the shelf life of meat and marine products in the packaging process. *Food Packaging and Shelf Life*, *29*, Article 100722. https://doi.org/10.1016/j.fpsl.2021.100722
10. Muranko, Ż., Tassell, C., Zeeuw van der Laan, A., Aurisicchio, M. (2021). Characterisation and environmental value proposition of reuse models for fast-moving consumer goods: Reusable packaging and products. *Sustainability*, 13(5), Article 2609. https://doi.org/10.3390/su13052609
11. Qian, M., Liu, D., Zhang, X., Yin, Z., Ismail, B. B., Ye, X. et al. (2021). A review of active packaging in bakery products: Applications and future trends. *Trends in Food Science and Technology*, 114, 459–471. https://doi.org/10.1016/j.tifs.2021.06.009
12. Mendes, A. C., Pedersen, G. A. (2021). Perspectives on sustainable food packaging: — Is bio-based plastics a solution? *Trends in Food Science and Technology*, 112, 839–846. https://doi.org/10.1016/j.tifs.2021.03.049
13. Deshmukh, R. K., Gaikwad, K. K. (2024). Natural antimicrobial and antioxidant compounds for active food packaging applications. *Biomass Conversion and Biorefinery*, 14(4), 4419–4440. https://doi.org/10.1007/s13399-022-02623-w
14. Deshwal, G. K., Panjagari, N. R., Alam, T. (2019). An overview of paper and paper based food packaging materials: Health safety and environmental concerns. *Journal of Food Science and Technology*, 56(10), 4391–4403. https://doi.org/10.1007/s13197-019-03950-z
15. Mazzola, N., Sarantópoulos, C. I. G. L. (2019). Packaging design alternatives for meat products. Chapter in a book: Food Processing. IntechOpen, 2019. http://doi.org/10.5772/intechopen.88586
16. Bras, J., Saini, S. (2017). Nanocellulose in functional packaging. Chapter in a book: Cellulose-reinforced nanofibre composites. Woodhead Publishing, 2017. https://doi.org/10.1016/B978-0-08-100957-4.00008-5
17. Ebnesajjad, S. (2012). Plastic films in food packaging: Materials, technology and applications. William Andrew, 2012. https://doi.org/10.1016/C2012-0-00246-3
18. Jan, B., Rizvi, Q. u. e. H., Shams, R., Dar, A. H., Majid, I., Khan, S. A. (2022). Containers for food packaging application. Chapter in a book: Micro-and Nano-containers for Smart Applications. Singapore: Springer Nature Singapore, 2022. https://doi.org/10.1007/978-981-16-8146-2_5
19. Anukiruthika, T., Sethupathy, P., Wilson, A., Kashampur, K., Moses, J. A., Anandharamakrishnan, C. (2020). Multilayer packaging: Advances in preparation techniques and emerging food applications. *Comprehensive Reviews in Food Science and Food Safety*, 19(3), 1156–1186. https://doi.org/10.1111/1541-4337.12556
20. Ananda, A. P., Manukumar, H. M., Umesha, S., Soumya, G., Priyanka, D., Kumar, A. M. et al. (2017). A relook at food packaging for cost effective by incorporation of novel technologies. *Journal of Packaging Technology and Research*, 1(2), 67–85. https://doi.org/10.1007/s41783-017-0011-4
21. Liu, Z., Zhang, M., Bhandari, B., Wang, Y. (2017). 3D printing: Printing precision and application in food sector. *Trends in Food Science and Technology*, 69, 83–94. https://doi.org/10.1016/j.tifs.2017.08.018
22. Andrady, A. L. (2015). Plastics and environmental sustainability. John Wiley and Sons, 2015.

23. Napper, I. E., Thompson, R. C. (2019). Environmental deterioration of biodegradable, oxo-biodegradable, compostable, and conventional plastic carrier bags in the sea, soil, and open-air over a 3-year period. *Environmental Science and Technology*, 53(9), 4775–4783. https://doi.org/10.1021/acs.est.8b06984
24. Lebreton, L., Andrady, A. (2019). Future scenarios of global plastic waste generation and disposal. *Palgrave Communications*, 5, Article 6. https://doi.org/10.1057/s41599-018-0212-7
25. Haward, M. (2018). Plastic pollution of the world's seas and oceans as a contemporary challenge in ocean governance. *Nature Communications*, 9, Article 667. https://doi.org/10.1038/s41467-018-03104-3
26. European bioplastics. (2021). Bioplastics market development update 2021. Retrieved from https://docs.europeanbioplastics.org/publications/market_data/Report_Bioplastics_Market_Data_2021_short_version.pdf Accessed April 24, 2024
27. Younes, M., Aggett, P., Aguilar, F., Crebelli, R., Filipič, M., Frutos, M. J. et al. (2017). Re-evaluation of alginic acid and its sodium, potassium, ammonium and calcium salts (E400 — E404) as food additives. *EFSA Journal*, 15(11), Article 5049, https://doi.org/10.2903/j.efsa.2017.5049
28. Acquavia, M. A., Pascale, R., Martelli, G., Bondoni, M., Bianco, G. (2021). Natural polymeric materials: A solution to plastic pollution from the agro-food sector. *Polymers*, 13(1), Article 158. https://doi.org/10.3390/polym13010158
29. Krishani, M., Shin, W. Y., Suhaimi, H., Sambudi, N. S. (2023). Development of scaffolds from bio-based natural materials for tissue regeneration applications: A review. *Gels*, 9(2), Article 100. https://doi.org/10.3390/gels9020100
30. Calva-Estrada, S. J., Jiménez-Fernández, M., Lugo-Cervantes, E. (2019). Protein-based films: Advances in the development of biomaterials applicable to food packaging. *Food Engineering Reviews*, 11(2), 78–92. https://doi.org/10.1007/s12393-019-09189-w
31. Miteluț, A. C., Popa, E. E., Drăghici, M. C., Popescu, P. A., Popa, V. I., Bujor, O. C. et al. (2021). Latest developments in edible coatings on minimally processed fruits and vegetables: A review. *Foods*, 10(11), Article 2821. https://doi.org/10.3390%2Ffoods10112821
32. Thombare, N., Kumar, S., Kumari, U., Sakare, P., Yogi, R. K., Prasad, N. et al. (2022). Shellac as a multifunctional biopolymer: A review on properties, applications and future potential. *International Journal of Biological Macromolecules*, 215, 203–223. https://doi.org/10.1016/j.ijbiomac.2022.06.090
33. Jurić, M., Bandić, L. M., Carullo, D., Jurić, S. (2024). Technological advancements in edible coatings: Emerging trends and applications in sustainable food preservation. *Food Bioscience*, 58, Article 103835. https://doi.org/10.1016/j.fbio.2024.103835
34. Song, D.-H., Hoa, V. B., Kim, H. W., Khang, S. M., Cho, S.-H., Ham, J.-S. et al. (2021). Edible films on meat and meat products. *Coatings*, 11(11), Article 1344. https://doi.org/10.3390/coatings11111344
35. Kocira, A., Kozłowicz, K., Panasiewicz, K., Staniak, M., Szpunar-Krok, E., Hortyńska, P. (2021). Polysaccharides as edible films and coatings: Characteristics and influence on fruit and vegetable quality — A review. *Agronomy*, 11(5), Article 813. https://doi.org/10.3390/agronomy11050813
36. Suhag, R., Kumar, N., Petkoska, A. T., Upadhyay, A. (2020). Film formation and deposition methods of edible coating on food products: A review. *Food Research International*, 136, Article 109582. https://doi.org/10.1016/j.foodres.2020.109582
37. Gheorghita (Puscaselu), R., Gutt, G., Amariei, S. (2020). The use of edible films based on sodium alginate in meat product packaging: An eco-friendly alternative to conventional plastic materials. *Coatings*, 10(2), Article 166. https://doi.org/10.3390/coatings10020166
38. Tkaczewska, J. (2020). Peptides and protein hydrolysates as food preservatives and bioactive components of edible films and coatings-A review. *Trends in Food Science and Technology*, 106, 298–311. https://doi.org/10.1016/j.tifs.2020.10.022
39. Kandasamy, S., Yoo, J., Yun, J., Kang, H. B., Seol, K. H., Kim, H. W. et al. (2021). Application of whey protein-based edible films and coatings in food industries: An updated overview. *Coatings*, 11(9), Article 1056. https://doi.org/10.3390/coatings11091056
40. Singh, R., Dutt, S., Sharma, P., Sundramoorthy, A. K., Dubey, A., Singh, A. et al. (2023). Future of nanotechnology in food industry: Challenges in processing, packaging, and food safety. *Global Challenges*, *7*(4), Article 2200209. https://doi.org/10.1002/gch2.202200209
41. Mihalca, V., Kerezsi, A. D., Weber, A., Gruber-Traub, C., Schmucker, J., Vodnar, D. C. et al. (2021). Protein-based films and coatings for food industry applications. *Polymers*, 13(5), Article 769. https://doi.org/10.3390/polym13050769
42. Al-Tayyar, N. A., Youssef, A. M., Al-Hindi, R. (2020). Antimicrobial food packaging based on sustainable bio-based materials for reducing foodborne Pathogens: A review. *Food chemistry*, 310, Article 125915. https://doi.org/10.1016/j.foodchem.2019.125915
43. Wahab, Y. A., Al-Ani, L. A., Khalil, I., Schmidt, S., Tran, N. N., Escribà-Gelonch, M. et al. (2024). Nanomaterials: A critical review of impact on food quality control and packaging. *Food Control*, 163, Article 110466. https://doi.org/10.1016/j.foodcont.2024.110466
44. Kontominas, M. G., Badeka, A. V., Kosma, I. S., Nathanailides, C. I. (2021). Recent developments in seafood packaging technologies. *Foods*, 10(5), Article 940. https://doi.org/10.3390/foods10050940
45. Rashed, M. S., Sobhy, M., Pathania, S. (2022). Active packaging of foods. Chapter in a book: Shelf life and food safety. CRC Press, 2022.
46. Manzoor, A., Ahmad, S., Yousuf, B. (2023). Development and characterization of edible films based on flaxseed gum incorporated with Piper betle extract. *International Journal of Biological Macromolecules*, 245, Article 125562. https://doi.org/10.1016/j.ijbiomac.2023.125562
47. Sason, G., Nussinovitch, A. (2021). Hydrocolloids for edible films, coatings, and food packaging. Chapter in a book: Handbook of hydrocolloids. Woodhead Publishing, 2021. http://doi.org/10.1016/b978-0-12-820104-6.00023-1
48. Gagaoua, M., Bhattacharya, T., Lamri, M., Oz, F., Dib, A. L., Oz, E. et al. (2021). Green coating polymers in meat preservation. *Coatings*, 11(11), Article 1379. https://doi.org/10.3390/coatings11111379
49. Sierra, K. (2024). Engineering bioplastics with biopolymers and antimicrobials to improve listeria monocytogenes food safety in ready-to-eat foods over 12-week of storage. Master's thesis.
50. Umaraw, P., Munekata, P. E. S., Verma, A. K., Barba, F. J., Singh, V. P., Kumar, P. et al. (2020). Edible films/coating with tailored properties for active packaging of meat, fish and derived products. *Trends in Food Science and Technology*, 98, 10–24. https://doi.org/10.1016/j.tifs.2020.01.032
51. Zhao, Y., Teixeira, J. S., Saldaña, M. D., Gänzle, M. G. (2019). Antimicrobial activity of bioactive starch packaging films against Listeria monocytogenes and reconstituted meat microbiota on ham. *International Journal of Food Microbiology*, 305, Article 108253. https://doi.org/10.1016/j.ijfoodmicro.2019.108253
52. Farhan, A., Hani, N. M. (2020). Active edible films based on semi-refined κ-carrageenan: Antioxidant and color properties and application in chicken breast packaging. *Food*

Packaging and Shelf Life, 24, Article 100476. https://doi.org/10.1016/j.fpsl.2020.100476

53. Pirsa, S., Shamusi, T. (2019). Intelligent and active packaging of chicken thigh meat by conducting nano structure cellulose-polypyrrole-ZnO film. *Materials Science and Engineering: C*, 102, 798–809. https://doi.org/10.1016/j.msec.2019.02.021
54. Xiong, Y., Li, S., Warner, R. D., Fang, Z. (2020). Effect of oregano essential oil and resveratrol nanoemulsion loaded pectin edible coating on the preservation of pork loin in modified atmosphere packaging. *Food Control*, 114, Article 107226. https://doi.org/10.1016/j.foodcont.2020.107226
55. Sani, I. K., Geshlaghi, S. P., Pirsa, S., Asdagh, A. (2021). Composite film based on potato starch/apple peel pectin/ZrO_2 nanoparticles/Microencapsulated Zataria multiflora essential oil; Investigation of physicochemical properties and use in quail meat packaging. *Food Hydrocolloids*, 117, Article 106719. https://doi.org/10.1016/j.foodhyd.2021.106719
56. Bhagath, Y. B., Manjula, K. (2019). Influence of composite edible coating systems on preservation of fresh meat cuts and products: A brief review on their trends and applications. *International Food Research Journal*, 26(2), 377–392.
57. Souza, V. G. L., Rodrigues, C., Valente, S., Pimenta, C., Pires, J. R. A., Alves, M. M. et al. (2020). Eco-friendly ZnO/Chitosan bionanocomposites films for packaging of fresh poultry meat. *Coatings*, 10(2), Article 110. https://doi.org/10.3390/coatings10020110
58. Arkoun, M., Daigle, F., Holley, R. A., Heuzey, M. C., Ajji, A. (2018). Chitosan-based nanofibers as bioactive meat packaging materials. *Packaging Technology and Science*, 31(4), 185–195. https://doi.org/10.1002/pts.2366
59. Kowalska, H., Marzec, A., Domian, E., Kowalska, J., Ciurzyńska, A., Galus, S. (2021). Edible coatings as osmotic dehydration pretreatment in nutrient-enhanced fruit or vegetable snacks development: A review. *Comprehensive Reviews in Food Science and Food Safety*, 20(6), 5641–5674. https://doi.org/10.1111/1541-4337.12837
60. Chen, H., Wang, J., Cheng, Y., Wang, C., Liu, H., Bian, H. et al. (2019). Application of protein-based films and coatings for food packaging: A review. *Polymers*, 11(12), Article 2039. https://doi.org/10.3390/polym11122039
61. Álvarez-Castillo, E., Felix, M., Bengoechea, C., Guerrero, A. (2021). Proteins from agri-food industrial biowastes or co-products and their applications as green materials. *Foods*, 10(5), Article 981. https://doi.org/10.3390/foods10050981
62. Bharti, S. K., Pathak, V., Alam, T., Arya, A., Basak, G., Awasthi, M. G. (2020). Materiality of edible film packaging in muscle foods: A worthwhile conception. *Journal of Packaging Technology and Research*, 4(1), 117–132. https://doi.org/10.1007/s41783-020-00087-9
63. Hadidi, M., Jafarzadeh, S., Forough, M., Garavand, F., Alizadeh, S., Salehabadi, A. et al. (2022). Plant protein-based food packaging films; recent advances in fabrication, characterization, and applications. *Trends in Food Science and Technology*, 120, 154–173. https://doi.org/10.1016/j.tifs.2022.01.013
64. Catarino, M. D., Alves-Silva, J. M., Fernandes, R. P., Gonçalves, M. J., Salgueiro, L. R., Henriques, M. F. et al. (2017). Development and performance of whey protein active coatings with Origanum virens essential oils in the quality and shelf life improvement of processed meat products. *Food Control*, 80, 273–280. https://doi.org/10.1016/j.foodcont.2017.03.054
65. Zając, M., Jamróz, E., Guzik, P., Kulawik, P., Tkaczewska, J. (2021). Active biopolymer films based on furcellaran, whey protein isolate and Borago officinalis extract: Characterization and application in smoked pork ham production. *Journal of the Science of Food and Agriculture*, 101(7), 2884–2891. https://doi.org/10.1002/jsfa.10920
66. Ribeiro Sanches, M. A., Camelo-Silva, C., da Silva Carvalho, C., Rafael de Mello, J., Barroso, N. G., Lopes da Silva Barros, E. et al. (2021). Active packaging with starch, red cabbage extract and sweet whey: Characterization and application in meat. *LWT*, 135, Article 110275. https://doi.org/10.1016/j.lwt.2020.110275
67. Díaz-Montes, E., Castro-Muñoz, R. (2021). Edible films and coatings as food-quality preservers: An overview. *Foods*, 10(2), Article 249. https://doi.org/10.3390/foods10020249
68. Bupphatanarat, P., Powtongsook, W., Asawahame, C., Wongtrakul, P. (2020). Application of plant extracts as a preservative in an aqueous gel formulation. *Key Engineering Materials*, 859, 172–180. http://doi.org/10.4028/www.scientific.net/KEM.859.172
69. Nogueira, G. F., Oliveira, R. A. de, Velasco, J. I., Fakhouri, F. M. (2020). Methods of incorporating plant-derived bioactive compounds into films made with agro-based polymers for application as food packaging: A brief review. *Polymers*, 12(11), Article 2518. https://doi.org/10.3390/polym12112518
70. Gheorghita (Puscaselu), R., Amariei, S., Norocel, L., Gutt, G. (2020). New edible packaging material with function in shelf life extension: Applications for the meat and cheese industries. *Foods*, 9(5), Article 562. https://doi.org/10.3390/foods9050562
71. Giatrakou, V. I., Al-Daour, R., Savvaidis, I. N. (2023). Chitosan and hurdle technologies to extend the shelf life or reassure the safety of food formulations and ready-to-eat/cook preparations/meals. Chapter in a book: Chitosan: Novel Applications in Food Systems. Academic Press, 2023. https://doi.org/10.1016/B978-0-12-821663-7.00009-0
72. Fattahian, A., Fazlara, A., Maktabi, S., Bavarsad, N. (2020). The effects of edible chitosan coating containing Cuminum cyminum essential oil on the shelf-life of meat in modified atmosphere packaging. *Journal of Food Science and Technology (Iran)*, 17(104), 79–91. http://doi.org/10.52547/fsct.17.104.79
73. Bazargani-Gilani, B., Aliakbarlu, J., Tajik, H. (2015). Effect of pomegranate juice dipping and chitosan coating enriched with Zataria multiflora Boiss essential oil on the shelf-life of chicken meat during refrigerated storage. *Innovative Food Science and Emerging Technologies,* 29, 280–287. https://doi.org/10.1016/j.ifset.2015.04.007
74. Sogut, E., Seydim, A. C. (2019). The effects of chitosan-and polycaprolactone-based bilayer films incorporated with grape seed extract and nanocellulose on the quality of chicken breast fillets. *LWT*, 101, 799–805. https://doi.org/10.1016/j.lwt.2018.11.097
75. Utami, R., Khasanah, L. U., Nasution, M. I. A. (2017). Preservative effects of kaffir lime (Citrus hystrix DC) leaves oleoresin incorporation on cassava starch-based edible coatings for refrigerated fresh beef. *International Food Research Journal*, 24(4), 1464–1472.
76. Dharmalingam, K., Roy, A., Anandalakshmi, R. (2022). Essential Oils in Active Films and Coatings. *Biopolymer-Based Food Packaging: Innovations and Technology Applications*, 422–444. https://doi.org/10.1002/9781119702313.ch13
77. Yemiş, G. P., Candoğan, K. (2017). Antibacterial activity of soy edible coatings incorporated with thyme and oregano essential oils on beef against pathogenic bacteria. *Food Science and Biotechnology*, 26(4), 1113–1121. https://doi.org/10.1007/s10068-017-0136-9
78. da Rocha, M., Alemán, A., Romani, V. P., López-Caballero, M. E., Gómez-Guillén, M. C., Montero, P. et al. (2018). Effects of agar films incorporated with fish protein hydrolysate or clove essential oil on flounder (Paralichthys orbignyanus) fillets shelf-life. *Food Hydrocolloids*, 81, 351–363. https://doi.org/10.1016/j.foodhyd.2018.03.017
79. Mojaddar Langroodi, A., Tajik, H., Mehdizadeh, T., Moradi, M., Kia, E. M., Mahmoudian, A. (2018). Effects of sumac extract dipping and chitosan coating enriched with

Zataria multiflora Boiss oil on the shelf-life of meat in modified atmosphere packaging. *LWT*, 98, 372–380. https://doi.org/10.1016/j.lwt.2018.08.063
80. Dalvandi, F., Almasi, H., Ghanbarzadeh, B., Hosseini, H., Khosroshahi, N.K. (2020). Effect of vacuum packaging and edible coating containing black pepper seeds and turmeric extracts on shelf life extension of chicken breast fillets. *Journal of Food and Bioprocess Engineering*, *3*(1), 69–78. https://doi.org/10.22059/jfabe.2020.76631
81. Punia Bangar, S., Chaudhary, V., Thakur, N., Kajla, P., Kumar, M., Trif, M. (2021). Natural antimicrobials as additives for edible food packaging applications: A review. *Foods*, 10(10), Article 2282. https://doi.org/10.3390/foods10102282
82. Manzoor, A., Khan, S., Dar, A. H., Pandey, V. K., Shams, R., Ahmad, S. et al. (2023). Recent insights into green antimicrobial packaging towards food safety reinforcement: A review. *Journal of Food Safety*, 43(4), Article e13046. https://doi.org/10.1111/jfs.13046

AUTHOR INFORMATION

Kanza Saeed, MS (Food Technology), Lecturer, Institute of Food Science and Technology, Faculty of Natural Science, Khwaja Fareed University of Engineering and Information Technology. Abu Dhabi Road, Rahim Yar Khan, 64200 Pakistan. Tel.: +92–333–746–80–85, E-mail: kanza.saeed@outlook.com, kanza.saeed@kfueit.edu.pk
ORCID: https://orcid.org/0000–0003–1273–9753
* corresponding author

Zaryab Ali, MS(Agriculture Business), Deputy Section Manager, Sales Department, Charoen Pokphand Pakistan Pvt. Ltd. 18-A Commercial Zone Phase-5, DHA, Lahore, Pakistan. Tel.: +92–333–623–04–14, E-mail: zaryabali1809@gmail.com
ORCID: https://orcid.org/0000–0001–6966–011X

All authors bear responsibility for the work and presented data.

All authors made an equal contribution to the work.

The authors were equally involved in writing the manuscript and bear the equal responsibility for plagiarism.

The authors declare no conflict of interest.