coatings

Review

Innovations in the Packaging of Meat and Meat Products—A Review

Marian Gil and Mariusz Rudy *

Department of Agricultural Processing and Commodity Science, Institute of Food and Nutrition Technology, College of Natural Sciences, University of Rzeszow, Zelwerowicza 4, 35-601 Rzeszow, Poland
* Correspondence: mrudy@ur.edu.pl; Tel.: +48-0-17-785-52-60

Abstract: This study aims to systematize the knowledge about innovative solutions to understand the composition of packaging materials and bioactive substances used in the packaging processes of meat and meat products, given the contemporary trends and consumer expectations. In edible packaging, the application of natural and renewable biopolymers is gaining popularity as, unlike petroleum-based plastic packaging materials, they do not cause environmental problems. Packaging using active compounds further extends the shelf life of food products compared with traditional packaging by reducing the adverse effects during storage, such as oxidation, microbial growth, and moisture loss. On the other hand, the inclusion of natural bioactive substances in packaging provides an opportunity to increase the shelf life of food products and/or decrease the use of preservatives. This direction offers a wide field for research due to the multitude of substances, their impact, and the properties of the packaged product.

Keywords: active packaging; electrospinning; bioactive substances

check for updates

Citation: Gil, M.; Rudy, M. Innovations in the Packaging of Meat and Meat Products—A Review. *Coatings* **2023**, *13*, 333. https://doi.org/10.3390/coatings13020333

Academic Editors: Jun Mei and Jing Xie

Received: 24 December 2022
Revised: 23 January 2023
Accepted: 29 January 2023
Published: 1 February 2023

1. Introduction

Petroleum-based plastics are one of the most commonly used packaging materials due to their stiffness, flexibility, desirable barrier properties, inexpensiveness, and ease of processing [1]. As conventional packaging materials for meat or meat products, synthetic materials in the form of foil are used, often in combination with, e.g., cardboard outer packaging. The most commonly used synthetic plastics for meat packaging include the following: polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), polyester (PET), polyamide (PA), polyvinylidene chloride (PVDC), and ethylenvinyl alcohol [2]. However, the mass use of such materials has resulted in serious environmental problems, such as the depletion of natural resources, garbage pollution, and global warming, as they are both nonrenewable and nondegradable [3–5].Therefore, the efforts of scientists and industry have been directed towards sustainable strategies by developing innovations in the field of packaging materials and packaging methods [6]. An expected property of new packaging materials is that they are reusable, recyclable, or biodegradable once they have served their purpose [7,8]. Therefore, the food industry is looking for an environmentally friendly replacement of non-biodegradable plastics with biodegradable plastics [9].

Active packaging (AP) is a novel packaging method that utilizes various active compounds such as antioxidants, antimicrobials, moisture absorbers, gas absorbers, and ultraviolet absorbers. These active components interact with the packaged food product or the surrounding environment to extend its shelf life by maintaining food quality, safety, and integrity. Compared with traditional packaging, packaging using active compounds further extends the shelf life of food products by reducing the harmful effects during storage, such as oxidation, microbial growth, and moisture loss [6,10].

Recently, there has been huge progress in the construction of AP systems using various methods such as dip coating [11], layer-by-layer assembly [12], electrospinning [13], solvent casting [14], extrusion [15], and homogeneous emulsification [16,17]. AP technologies can be based on either synthetic or natural materials, and some of them contain active ingredients such as antioxidants, antimicrobials, vitamins, flavors, and dyes [18]. In edible packaging, using natural and renewable biopolymers is gaining popularity as they, unlike petroleum-based plastic packaging materials, do not cause environmental problems. In edible films, substances that comply with food regulations should be present, and these films need to be economical, easy to apply, and environmentally friendly [19]. Edible films are classified based on their structural material, namely hydrocolloids (polysaccharides and proteins), lipids, and composites [20]. The limitation for edible packaging is the risk of their contamination and thus becoming inedible. Regardless, if not eaten, edible packaging is inherently biodegradable [21]. New packaging materials ensure higher functionality of the packaging, extending the shelf life and ensuring higher quality and safety of packaged meat [7]. Currently, many novel AP materials are gaining huge interest in the food industry. AP can inhibit the growth of microorganisms on the surface of the food product, enhance its nutritional and sensory properties, increase the shelf life of some food products, and decrease the environmental impact of packaging [22]. As a novel method, innovative packaging not only extends the quality and shelf life of the food product but also monitors its quality during transport and storage. AP and intelligent packaging have been adopted of late to ensure the traceability, safety, and quality of food products [23,24]. The main task of intelligent packaging is to capture and provide information about changes in the quality of packaged goods during transport and storage. They provide information about the conditions of the packaged product, without affecting its quality [25].

In contrast to traditional food packaging, functionalized packaging systems that are developed to load various bioactive compounds in matrix materials can lead to wide-ranging biological effects such as antibacterial and antioxidant effects and thus protect the food product from harmful environmental factors [26–28]. Active packages are developed by embedding a plant-based bioactive material in a polymer. Essential oils are in the spotlight as active ingredients due to their antimicrobial and antioxidant properties [29,30].

This study aimed to systematize the knowledge about innovative solutions to understand the composition of packaging materials and bioactive substances used in the packaging of meat and meat products, given the contemporary trends and consumer expectations. This will help demonstrate the positive effects of using innovative methods in the packaging of meat and its products.

2. Natural Polymers in Food Packaging

The environmental problems caused by conventional polymers have necessitated the search for alternative packaging materials. Biodegradable films based on biopolymers have become such an alternative [31]. In 2020, bio-based plastics used in food packaging amounted to 0.99 million tons, accounting for 47% of the total production of bio-based plastics [1]. The raw materials for the production of biopolymers are relatively plentiful, and the production of biopolymers consumes agricultural waste, which, together with the environmental benefits, makes the production of biopolymers profitable [32].

Biopolymers are popular in food packaging because they are edible and safer for humans. For applications in food packaging, the most frequently studied nanocomposite biomaterials are proteins, carbohydrates, and their derivatives [33–36]. To achieve an environmentally friendly alternative and promote sustainability goals, cellulose- and starch-based nanocomposites can be incorporated into packaging systems [37]. Examples of natural antioxidants for lipid food include, among others, edible films and coatings with an active coating based on cellulose derivatives, chitosan, alginate, galactomannans, or gelatin [38].

Cellulose is the most abundant biopolymer in the world, making it an ideal raw material for use in sustainable packaging materials. Cellulose ethers, such as methylcellulose, hydroxypropylcellulose, hydroxypropylmethylcellulose, and carboxymethylcellulose, are suitable for the production of packaging films [7,39]. Cellulose is obtained from natural sources such as wood, cotton and food waste, agricultural waste, cereal bran, and fruit skins [40]. Its availability from many different sources and being biodegradable, environmentally friendly, and inexpensive have made cellulose an often-preferred material in packaging [41]. Besides being edible and biodegradable, its sensory and organoleptic properties are beneficial; therefore, cellulose can be used in the encapsulation of bioactive substances to enhance the nutritional properties of food products [40].

Starch is one of the most crucial biodegradable polymers because of its abundance, low cost, biodegradability, and renewability [42,43]. Starch-based films have been used in food packaging and preservation technologies as they show excellent film-forming ability and unique gelatinization properties, along with their odorless, tasteless, and colorless nature [5,44]. So far, starch-based films have been extensively used in the packaging of different types of food products (such as meat, fruit, oil, and cheese) as they have good organoleptic and gas barrier properties [45,46]. However, starch-based materials are brittle and hydrophilic, which limits their processing and use. Starch is mixed with various synthetic and natural polymers to improve its properties; this increases the strength of the processing properties of the materials [47].

Another biopolymer is chitosan, which is derived from chitin. Chitosan films have shown good antibacterial and antioxidant performance for food packaging. The amino and hydroxyl groups in the structure of chitosan affect its antimicrobial activity against gram-positive and gram-negative bacteria [48]. Chitosan-based films have a high gas barrier. Their brittleness eliminates the use of plasticizers such as polyols (glycerin, sorbitol, and polyethylene glycol) or fatty acids (stearic and palmitic) [47].

Being a water-soluble natural polymer, gelatin is a protein of biological origin, which shows high biodegradability, biocompatibility, water absorption, nonimmunogenicity, and commercial availability. Thanks to these properties, various forms of gelatin (e.g., foils, scaffolds, capsules, filters) are used in cosmetics, pharmacy, medicine, food, and water filtration [49]. However, due to its hydrophilicity, its structure needs to be stabilized because, in the absence of biopolymer stabilization, gelatin-based materials tend to dissolve and lose their structure [50].

Among the methods available for gelatin structure stabilization, protein crosslinking is one of the most commonly used approaches to achieving hydrolytic stability of samples based on gelatin [51]. Crosslinkers such as glutaraldehyde and genipin are extensively used in this regard. However, there exist potential toxicity issues, along with the need for intensive detoxification strategies considering residual unreacted glutaraldehyde groups. In addition, the high cost of genipins is one of the primary disadvantages while using these crosslinkers [51,52]. The gelatine-based packaging material has a good oxygen barrier compared to other biopolymers and has the ability to be welded, which is important in the production of packaging. The production of gelatin foils is relatively simple; it does not require special conditions for drying and forming the foil [53]. To prevent the risk of toxicity and achieve cost-effectiveness, heat treatment of gelatin along with sugar particles has recently been introduced as an alternative chemical crosslinking method [54,55]. The resulting condensation reaction between proteins and sugar is called the Maillard reaction (MR) [50].

Gelatin-based materials show different properties (e.g., solubility, swelling, antioxidant activity, preservation of morphology after immersion) based on the degree of MR, which depends on parameters such as type of sugar, reaction time, temperature, and pH of the solution. As crosslinkers, pentoses (e.g., ribose) are more reactive than hexoses (e.g., glucose) and disaccharides (e.g., lactose) [56], whereas an increase in the percentage of sugar (up to a certain point), temperature, or pH of the solution induces a further extended response [50,57,58].

To enhance the bioavailability and stability of thiamine in raw and cooked red meat and salmon samples, the thiamine nanofiber nanocoating process has been successfully applied. Specifically, for salmon samples, this process is found to be more effective regarding bioavailability. In addition, it ensures a continuous increase in the thiamine content in red meat and fish samples under cold storage conditions for 3 days. Whereas a maximum bioavailability of 87% was reported for nanocoated red meat samples, for salmon samples, a 94% bioavailability was achieved. Therefore, given these results, in future, this nanotechnology application may play a leading role in the food industry [59].

The most successful edible protein film available on the market is a sausage casing made of collagen. The films reduce leakage and prevent discoloration and fat oxidation of thawed and chilled beef steaks. Collagen-based films are used for processed meats to increase juiciness, reduce drip. For many years, the Japanese meat industry has commercially used films and coatings based on polysaccharides. During processing, the coatings dissolve and integrate with the meat, which has a positive effect on the texture and reduces weight loss, ensuring higher yield [60].

3. Electrospinning

Nanofibers are obtained using electrospinning techniques that use electrostatic forces to form fibers and non-electrospinning techniques that use mechanical force. These include phase separation, drawing, template synthesis, self-assembly, etc. [61].

Electrospinning is a versatile, cost-effective, and convenient method to produce nano-/microfibers with a high surface-area-to-volume ratio, controlled dimensions, high load capacity, low weight, and wide-ranging flexibility [62]. Furthermore, with decades of evolution, electrospinning nanofibers can now be designed with various structures and morphologies to perform specific functions, such as uniaxial [63], hollow [64], core–shell [65], and porous structures [66].

Electrospinning is an easy and versatile nanotechnique for producing nonwoven nanofiber films. Its advantages are as follows: a high surface-area-to-volume ratio, increased porosity, small interfibrous pore size, and high gas permeability. It is widely used in natural and synthetic polymers [5,67]. Thus, electrospinning has gained interest in, among others, textiles, agriculture, water treatment, air filtration, energy storage, cosmetics, electronics and sensors, pharmaceuticals, biomedical products, and packaging [49,50,68].

Among innovative approaches to packaging, electrospinning has gained huge interest in the biomedical and the food industries, especially in meat packaging [23,69–72]. The rapid development of electrospinning has resulted in numerous applications in various fields, including biomedicine [73], food packaging [74], sensors [75], protective materials [76], textiles [77], energy [78], oil–water separation, and others [17,79]. Several applications of electrospinning have been found in food science, e.g., protecting bioactive ingredients from external factors by encapsulating them [80–82] and extending the shelf life of a food product by improving its bioavailability and controlled release of biomolecules [83–85].

Compared with traditional casting films, electrospun nanofibers show numerous unique characteristics such as high surface-area-to-volume ratio, nanoporous structure, high porosity, and high absorption capacity [62,86], which make them more sensitive to the surrounding changes in acidity/alkalinity and make it possible to control the release of the contained bioactive compounds. Thus, of late, electrospun nanofibers have gained much attention in developing food packaging films [14,87,88].

In addition, being a nonthermal process, electrospinning helps maintain the structure stability, particularly when using additives with low thermal stability at high temperatures. The process of electrospinning can be briefly divided into three steps as follows: (1) formation of a conical shape ("tailor's cone") by a charged drop of a polymer solution; (2) formation of a jet at the end of the cone if the electric field strength is sufficient to overcome the viscoelastic force of the solution; and (3) deposition of a solid jet on the collector surface and production of many fibers, with rapid volatilization of the solvent [5,89]. To obtain fibers using solution electrospinning, various materials—including synthetic and natural polymers and their combinations—can be utilized. Among them, synthetic polymers such as polystyrene and polyvinyl chloride, biocompatible and biodegradable synthetic polymers like polylactic acid and polylactic-co-glycolic acid, conductive polymers such as polyaniline and polypyrrole, and natural polymers such as chitosan, alginate, collagen, and gelatin can be directly electrospun into nanofibers [50,90–94].

The electrospinning technique has been used to develop high-performance packaging materials in the food industry, due to its unique advantages: it can produce (1) micro-/nanofibers to encapsulate unstable bioactive molecules and load with nanoparticles; (2) edible packaging nanofibers from biopolymers, which show excellent biosafety; and (3) nanofibers for the controlled release of bioactive compounds under a specific stimulus [17].

Natural polymers, especially polysaccharides and proteins, are frequently used to produce nanofibers due to their biocompatibility, nontoxicity, food-grade properties, and biodegradability [95]. In addition, their diversity of functional groups enables a wide range of active ingredients to be bound or trapped using molecular interactions [96]. Functional electrospun mats can be used to develop nanocomposite material from a diverse range of performance-enhanced plastics for packaging applications. In addition, they can be used to reinforce the physical properties of both plastics and bioplastics as transparent gas barrier layers or even as new technologies for designing bioactive packaging with antimicrobial protection and delivering nutraceuticals to food products [97]. Numerous electrospinning stimuli-responsive materials have recently been synthesized, which can achieve the controlled release of active substances, thus producing a long-term biological effect [98,99].

Nanofiber mats are promising candidates in AP [100]. In the AP industry, nanofibers are highly useful tools to protect and deliver bioactive compounds to their destination at the desired time [101,102]. Electrospun nanofibers can improve the barrier and antimicrobial properties of materials in food packaging depending upon their functional properties. These nanofibers can also be utilized as nanosensors to detect and monitor the conditions of the food product during transport and storage [103]. These biological polymers can be based on proteins, lipids, or polysaccharides [104–106]. This advanced technology is originally derived from the enrichment of antioxidants in packaging designs [107–110].

Electrospun fibers show a good capacity to charge active substances, and their huge surface area leads to a rapid response to internal and/or external factors by releasing/activating the trapped compounds in a timely manner [90,95,111].

Thus, as a new technology, electrospinning can improve the overall quality and extend the shelf life of fresh or packaged meat products [95], including (1) protecting products from microbial contamination [3,71,112], (2) preventing lipid and protein oxidation [113,114], (3) developing sensory properties [70,84], and (4) improving the functional and nutritional characteristics of meat products [22]. Electrospinning enables the incorporation of antimicrobial compounds into the matrixes/or packaging mats and allows for a functional effect on the surface of meat or products—where the microbiological activity is located—instead of mixing them directly with food [115].

Starch-based films with nanofibers show an extremely high surface activity, which makes them potential candidates for active food packaging due to their nanosize [17]. In addition, the morphology and structure of electrospun starch fibers can be easily altered to protect numerous active substances and enhance the mechanical and barrier properties [116]. Several factors like fiber orientation, additional ingredients [117,118], and final processing [119] can influence their properties required for food packaging [5].

Results show that zein-based coatings are more suitable in the packaging of food products with a high water content [120]. Yildiz et al. [121] developed an electrospun chitosan/polyethylene/curcumin nanofiber to monitor the freshness of chicken meat. Duan et al. [14] showed that curcumin-loaded nanofibers provide the ability to monitor chicken spoilage in the real world.

The challenge is to overcome the unreliability of bio-based plastics. There is a need to develop a multilayer mixture using additives [1]. In conclusion, electrospinning seems to be a promising technique with potential applications in the fields of functional food products and AP [102]. The advantage of electrospinning is its simplicity, the possibility of using it in a wide range of materials, and its low cost [61].

4. Antioxidant and Antimicrobial Compounds

Many meat products are considered highly perishable because of their high nutrient content. Temperature is the major factor in the activation of the growth of microorganisms and chemical reactions; thus, the cooling temperature has a significant impact on their properties. However, variations in the temperature during storage and transport can impair the quality of the products, e.g., by increasing microbial growth and chemical reactions such as increasing peroxides and thiobarbituric acid (TBA) values [122,123].

To increase the commercial value and safety of beef, cold storage methods and cold chain logistics have been developed and widely used. These methods are used in preserving raw beef, especially in freezing and chilling [124,125]. Freezing below −18 °C significantly extends the shelf life of meat products but degrades the quality of the meat in the freezing–thawing process. In comparison, storage at 4 °C can preserve the sensory quality of meat and lower the energy consumption; however, it cannot inhibit the growth of microbes completely, in particular some psychrophiles, so the shelf life of the products is limited [28,124].

The meat industry is interested in achieving packaging durability goals and producing modern solutions based on bio-based, biodegradable, compostable, recyclable, or reusable materials [126]. Increasing demand for meat has urged significant advances in meat packaging, guaranteeing healthy and safe products. Meanwhile, the safety and quality of meat are dependent on the packaging materials and technologies applied [112,127].

Innovations in food packaging nanomaterials are primarily attributable to their following distinct characteristics: excellent optical, barrier, and thermal properties, antimicrobial activity, and advanced sensing properties affecting their chemical, physical, and biological potential unlike their bulk counterparts [37,128].

Nanomaterials consisting of TiO_2 [129,130], SiO_2 [131,132], AgNPs [133], graphene [134], and nanocellulose [135] possess remarkable characteristics such as high catalytic activity and conductivity, which make them quintessential candidates for biosensory abilities [37].

Exemplary electrochemical immunosensors that are appropriate for the detection of *Salmonella* in meat samples have recently been found in the literature [136]. For example, graphene is a fully reliable biosensing nanomaterial that can be easily integrated with smart packaging systems. Graphene-based nanofibers and electrodes are applied in the development of a flexible detector for ethanol [137], histamine [138], and ammonia [37,139]. Among these films, pigment-based natural colorimetric films have gained considerable attention due to their nontoxicity, biocompatibility, nature of pH sensing, and others [140,141]. These pH-sensitive colorimetric films can show visible color changes while reacting with non-neutral volatile gases generated from high-protein degraded food products, which can provide visual information about the quality and microbial contamination of the food product [14,86,142,143].

To delay lipid oxidation and reduce chemical additives causing health disorders, functional packaging using natural antioxidants is applied to extend the shelf life of meat products [112,144,145].

Antioxidant and antimicrobial compounds used in food packaging are of different origins: natural, such as essential oils, nisin, curcumin, α-tocopherol and vitamins, phenolic-rich plant and pomace extracts, allyl isothiocyanate, and chitosan [146,147]; synthetic antioxidants, such as butylhydroxytoluene and its analogs, butylhydroxyanisole, and t-butylhydroxyquinone [23]; or antimicrobial, such as organic acids (acetic, sorbic and ascorbic, benzoic and propane), nitrites, and nitrates [148,149].

Thymol, which is the primary component of thyme oil (classified as Generally Recognized As Safe by United States Food and Drug Administration), is a promising alternative to chemical preservatives with good antimicrobial and antioxidant properties [150]. Although thymol's potential as a food preservative has been widely discussed, its use in film/coating formulations is highly limited due to its high volatility and hydrophobicity [151]. Given these issues, particular attention has been paid to the encapsulation of plant-derived bioactive compounds in biopolymer nanocarriers [26,28]. Lin et al. [152] used gelatin nanofibers that contain thyme essential oil/ε-polylysine β-cyclodextrin nanoparticles to control the growth of *Campylobacter jejuni* on the surface of poultry with no effects on the sensory and textural properties and color. The packaged chicken samples showed lower aerobic bacteria counts, total volatile basic nitrogen, trimethylamine and TBA content, and pH values [123].

Cinnamaldehyde (3-phenyl-2-propenal), a component of natural cinnamon oil with a common flavor, is one of the important antioxidant and antimicrobial agents. It can be used to improve the quality of food products and extend their shelf life. Its sensitivity to heat, light, humidity, oxygen, and liquid form at room temperature necessitates its encapsulation. Zein nanofiber mass containing 1000 ppm loaded with cinnamaldehyde showed good bactericidal activity against *Staphylococcus aureus* PTCC 1337 (Persian Type Culture Collection (PTCC)) and *Escherichia coli* O157:H7 with no significant adverse effects on texture or color in nitrite-reduced sausages [123]. The number of *E. coli* and *S. aureus* (colony-forming unit/g samples) decreased in all sausages during storage due to the presence of zein nanofibers with cinnamaldehyde as an antibacterial agent and nitrates [123]. Many studies [84,153–155] reported that cinnamaldehyde, zein nanofibers with cinnamaldehyde, and nitrites show long-term growth inhibition of *S. aureus* and *E. coli*. After 10 days of storage, samples with packages containing phase change materials used for temperature buffering did not contain *E. coli* and *S. aureus* bacteria [123].

Using unstable substances in AP, positive results are observed in nanoencapsulation techniques, including nanoparticles, nanoemulsions, and nanocapsules. This prevents the degradation of, for example, saffron bioactive compounds under adverse conditions until they are delivered for physiological purposes [156]. In this context, electrospinning and electrospraying have recently gained increased interest in encapsulating bioactive ingredients and food packaging. These methods are simple, versatile, nonthermal, and thus highly suitable for the encapsulation of heat-sensitive compounds [157–159]. Studies [159] have indicated that electroyarn containing 30% zein and 10% saffron extract show great potential in extending the shelf life of seafood products and delaying their spoilage during cold storage.

An overview of sample compositions of novel packaging materials, as well as the bioactive substances used and the spectrum of their effects on the quality of packaged food products, is presented in Table 1.

Table 1. Examples and effects of using bioactive substances in packaging materials.

Substance	Matrix	Positive Effects Obtained	Product	Source
		Antimicrobial effect		
Tea tree oil	Nanofiber membrane	Inhibition of 99.99% *Salmonella* after 4 days of operation without affecting the sensory quality	Chicken meat	[160]
Cinnamon essential oil (as core)	Encapsulated in Eudragit L100 (as a shell) by coaxial electrospinning technology	Controlled release, good antibacterial efficacy against *E. coli* and *S. aureus*	Pork loin	[161]
Pomegranate peel extract (PE)	Electrospun chitosan/polyethylene oxide (CS/PEO) active nanofibers/active CS/PEO/PE nanofibers	Effective inhibition of *E. coli* O157:H7 on samples at 4 and 25 °C for 7 and 10 days, respectively, compared to control packaging	Beef	[112]
Thyme (EO)	Silk fibroin nanofibers	*Salmonella typhimurium* reduction from 6.64 to 2.24 log CFU/g	Chicken meat	[70]

Table 1. *Cont.*

Substance	Matrix	Positive Effects Obtained	Product	Source
Oregano (EO)	Sodium alginate foil	A reduction in *Listeria* population of approximately 1.5 log at 8 °C and 12 °C at the end of storage and almost 2.5 log at 4 °C	Ham	[162]
Chitosan	Electrospun fibers based on chitosan and poly(ethylene oxide) CS/PEO	The ability to maintain safety and extend the shelf life by a week	Fresh red meat	[163]
Gallic acid + chitosan or carvacrol + chitosan	Starch foil	Complete inhibition of the growth of *Listeria monocytogenes* for 4 weeks of storage, starch films filled with chitosan or chitosan and carvacrol delayed the growth of the microbiota by 1–2 weeks	Ham	[164]
Electrospun gelatin-glycerine-ε-polylysine nanofibers	Gelatine	Growth inhibition of *L. monocytogenes*	Beef	[165]
Lemon (LEO)	Thermally stable and porous vermiculite (VML), LEO/VML complex, coupled with konjac glucomannan-grafted-poly (acrylic acid)/polyvinyl alcohol composite	Long-term LEO control release effectively inhibiting *E. coli* growth during storage, thus extending the shelf life of chilled pork by 3 days	Pork	[166]
Methyl ferulate	Zein	Effectively inhibition of microorganism growth in fish meat and slowing down of the production and accumulation of alkaline substances, thus controlling the increase in pH and maintaining freshness	Fish	[167]
Thyme EO/ε-polylysine β-cyclodextrin nanoparticles	Gelatin nanofibers	Controls the growth of *C. jejuni* on the surface of poultry without affecting the sensory evaluation	Poultry meat	[152]
Eugenol	Gelatin nanofibers	Strong antibacterial activity/growth retardation of total mesophilic aerobic and total psychrophilic bacteria	Meat products	[102]
Covered with poly-caprolactone/chitosan nonwoven fabric (film 1) covered with polycaprolac-tone/chitosan nonwoven fabric reinforced with *Colombian propolis* extract (film 2)	Linear low-density polyethylene film	Improving color stability and microbiological stability of pork samples	Pork	[168]
		Antioxidant effect		
Rosemary extract	Low-density polyethylene	Significant inhibition of lipid oxidation	Pork patties	[169]

Table 1. *Cont.*

Substance	Matrix	Positive Effects Obtained	Product	Source
Chitosan	Gelatin foil	Delaying the oxidation of fats and the formation of methemoglobin	Beef	[170]
Cinnamon (85%) + rosemary essential oil (15%)	Whey protein	Significant inhibition of lipid oxidation	Salami	[171]
Green tea extract	Polyamide	Very good antioxidant capacity and extending the shelf life from 6 to 23 days	Minced meat	[172]
		Antioxidant + antimicrobial action		
Beetroot peel extract	Gelatin–sodium alginate coating	Minimum inhibitory concentration of 2.5 mg/mL against Gram-positive bacteria (*S. aureus* and *E. coli*) and Gram-negative bacteria (*Salmonella enterica* and *L. monocytogenes*); delaying chemical oxidation and improving sensory characteristics	Beef meat	[173]
Lactobacillus plantarum postbiotics	Bacterial nanocellulose	Reduction (~5 log cycles) in the number of *L. monocytogenes* in minced meat. *L. plantarum* postbiotics showed moderate antioxidant activity in meat	Minced meat	[174]
Anethum graveolens (EO)	Plantago major seed mucosa	Action against *E. coli*, *S. aureus*, and fungi extending the shelf life of meat from 6 to 18 days; and inhibition of the growth of bacteria and slowing down of oxidative changes	Beef meat	[175]
Clove and argan oils	Poly(lactic acid) films coated with chitosan oil	Low oxygen permeability, high radical scavenging activity, and strong growth inhibition of *L. monocytogenes*, *S. typhimurium*, and *E. coli*	Beef meat	[176]
Aqueous green tea extract	Chitosan coating	Improvement in physicochemical properties (pH, color, and lipid oxidation) and microbiological properties of samples during storage; the inclusion of 0.1% and 0.5% green tea water extract in the 1% chitosan coating effectively retards the formation of malondialdehyde and microbial growth, while having a beneficial effect on the pH and intensity of red pork color	Pork cutlet with bone	[177]

Table 1. *Cont.*

Substance	Matrix	Positive Effects Obtained	Product	Source
ZnO nanoparticles with propolis	Composite film based on pullulan/chitosan (PLN/CTS)	Strong antibacterial activity against *E. coli* and *L. monocytogenes*: in meat samples wrapped in PLN/CTS/ZnO/PPS foil before packaging, the value of the total aerobic bacteria count (TABC) remained at the level of 6.7 Log CFU/g after 8 days of storage, controls showed a rapid increase (TABC) of ~6 Log CFU/g after 6 days and finally ~9 Log CFU/g within 8 days; excellent antioxidant activity: after 15 days of storage, while the peroxide values (PV) of packaged meat in the control group increased sharply to 22 meq/kg, meat wrapped in PLN/CTS/ZnO/PPS film showed a much lower peroxide count of ~10 meq/kg, showing approximately 55% reduced lipid oxidation	Pork loin	[178]
Catechin and lysozyme	Gelatin foil	Extending the shelf life and reducing the total number of bacteria, yeasts, and molds. Effective inhibition of lipid oxidation and microbial growth	Minced pork	[179]
Origanum virens (EO)	Whey protein concentrate (WPC)	Inhibition of total microbial load, higher acidity, and protection against discoloration; the EO-WPC film had a positive effect on the retardation of chain reactions of fat oxidation in alheiras	Traditional Portuguese sausages (paínhos and alheiras)	[180]
Terminalia arjuna extract	Maltodextrin and calcium alginate	Lipid oxidation was inhibited, and the number of yeasts and molds was reduced	Chevon sausages	[181]
Ethanol propolis extract	Chitosan film enriched with cellulose nanoparticle	*Pseudomonas* spp., *LAB* (lactic acid bacteria), and *Enterobacteriaceae* slow down the growth of microorganisms and the oxidation of lipids and proteins	Ground beef	[182]
Resveratrol	Gelatin/zein mats	Good antibacterial activity against *E. coli* and *S. aureus*, antioxidant activity to inhibit discoloration, and extended shelf life	Pork	[183]
Curcumin (CUR)	Packaging nanofibers based on gelatin/chitosan (GA/CS)	Inclusion of CUR significantly improved the antioxidant and antimicrobial activity of GA/CS/CUR nanofibers	Meat and seafood	[184]

Table 1. *Cont.*

Substance	Matrix	Positive Effects Obtained	Product	Source
Cloves (CL) and cinnamon (CI)	Corn starch (CS)	Inclusion of CL and CI EO in CS film at 3% significantly reduced the microbial population and thiobarbituric acid reactive substances (TBARS) values in raw meat during refrigerated storage	Beef	[185]
Spice EO (*Laurus nobilis*, LEO; and *Rosmarinus officinalis*, REO)	Polyvinyl alcohol electroyarn	Active packaging coatings containing LEO and REO extended the shelf life by reducing the process of lipid oxidation and reducing the number of *Listeria* during cold storage	Chicken breast fillets	[69]

5. Summary

The introduction of new technologies in food packaging has made the packaging market dynamic. This involves many changes in, among others, the verification of the usability of new materials in industrial conditions, especially in terms of their impact on the quality and safety of packaged food products. A promising direction is using natural polymers for this purpose, which offers a possibility to solve the problems as a result of the generation of huge amounts of waste by the food industry. However, the inclusion of natural bioactive substances in packaging provides an opportunity to extend the shelf life of food products and/or reduce the use of food preservatives. This provides a wide field for research due to the multitude of substances and the spectrum of their impact, together with the properties of the packaged product.

Author Contributions: Conceptualization, M.G. and M.R.; introduction, M.G. and M.R.; methodology, M.G. and M.R.; resources, M.G. and M.R.; writing—original draft preparation, M.G. and M.R.; writing—review and editing, M.G. and M.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Sid, S.; Mor, R.S.; Kishore, A.; Sharanagat, V.S. Bio-Sourced Polymers as Alternatives to Conventional Food Packaging Materials: A Review. *Trends Food Sci. Technol.* **2021**, *115*, 87–104. [CrossRef]
2. Cenci-Goga, B.T.; Iulietto, M.F.; Sechi, P.; Borgogni, E.; Karama, M.; Grispoldi, L. New Trends in Meat Packaging. *Microbiol. Res.* **2020**, *11*, 56–67. [CrossRef]
3. Nilsen-Nygaard, J.; Fernández, E.N.; Radusin, T.; Rotabakk, B.T.; Sarfraz, J.; Sharmin, N.; Sivertsvik, M.; Sone, I.; Pettersen, M.K. Current Status of Biobased and Biodegradable Food Packaging Materials: Impact on Food Quality and Effect of Innovative Processing Technologies. *Compr. Rev. Food Sci. Food Saf.* **2021**, *20*, 1333–1380. [CrossRef] [PubMed]
4. Zubair, M.; Ullah, A. Recent Advances in Protein Derived Bionanocomposites for Food Packaging Applications. *Crit. Rev. Food Sci. Nutr.* **2020**, *60*, 406–434. [CrossRef] [PubMed]
5. Zhu, W.; Zhang, D.; Liu, X.; Ma, T.; He, J.; Dong, Q.; Din, Z.; Zhou, J.; Chen, L.; Hu, Z.; et al. Improving the Hydrophobicity and Mechanical Properties of Starch Nanofibrous Films by Electrospinning and Cross-Linking for Food Packaging Applications. *LWT* **2022**, *169*, 114005. [CrossRef]
6. Li, X.; Zhang, R.; Hassan, M.M.; Cheng, Z.; Mills, J.; Hou, C.; Realini, C.E.; Chen, L.; Day, L.; Zheng, X.; et al. Active Packaging for the Extended Shelf-Life of Meat: Perspectives from Consumption Habits, Market Requirements and Packaging Practices in China and New Zealand. *Foods* **2022**, *11*, 2903. [CrossRef]

7. Schumann, B.; Schmid, M. Packaging Concepts for Fresh and Processed Meat—Recent Progresses. *Innov. Food Sci. Emerg. Technol.* **2018**, *47*, 88–100. [CrossRef]
8. Ingrao, C.; Giudice, A.L.; Bacenetti, J.; Khaneghah, A.M.; Sant'Ana, A.S.; Rana, R.; Siracusa, V. Foamy Polystyrene Trays for Fresh-Meat Packaging: Life-Cycle Inventory Data Collection and Environmental Impact Assessment. *Food Res. Int.* **2015**, *76*, 418–426. [CrossRef]
9. Agarwal, A.; Shaida, B.; Rastogi, M.; Singh, N.B. Food Packaging Materials with Special Reference to Biopolymers-Properties and Applications. *Chem. Afr.* **2022**, 1–28. [CrossRef]
10. Realini, C.E.; Marcos, B. Active and Intelligent Packaging Systems for a Modern Society. *Meat Sci.* **2014**, *98*, 404–419. [CrossRef]
11. Jung, S.; Cui, Y.; Barnes, M.; Satam, C.; Zhang, S.; Chowdhury, R.A.; Adumbumkulath, A.; Sahin, O.; Miller, C.; Sajadi, S.M.; et al. Multifunctional Bio-Nanocomposite Coatings for Perishable Fruits. *Adv. Mater.* **2020**, *32*, 1908291. [CrossRef]
12. Hu, B.; Chen, L.; Lan, S.; Ren, P.; Wu, S.; Liu, X.; Shi, X.; Li, H.; Du, Y.; Ding, F. Layer-by-Layer Assembly of Polysaccharide Films with Self-Healing and Antifogging Properties for Food Packaging Applications. *ACS Appl. Nano Mater.* **2018**, *1*, 3733–3740. [CrossRef]
13. Liu, M.; Wang, F.; Liang, M.; Si, Y.; Yu, J.; Ding, B. In Situ Green Synthesis of Rechargeable Antibacterial N-Halamine Grafted Poly(Vinyl Alcohol) Nanofibrous Membranes for Food Packaging Applications. *Compos. Commun.* **2020**, *17*, 147–153. [CrossRef]
14. Duan, N.; Li, Q.; Meng, X.; Wang, Z.; Wu, S. Preparation and Characterization of K-Carrageenan/Konjac Glucomannan/TiO_2 Nanocomposite Film with Efficient Anti-Fungal Activity and Its Application in Strawberry Preservation. *Food Chem.* **2021**, *364*, 130441. [CrossRef]
15. Huang, G.; Li, Y.; Qin, Z.; Liang, Q.; Xu, C.; Lin, B. Hybridization of Carboxymethyl Chitosan with MOFs to Construct Recyclable, Long-Acting and Intelligent Antibacterial Agent Carrier. *Carbohydr. Polym.* **2020**, *233*, 115848. [CrossRef]
16. Li, S.; Sun, J.; Yan, J.; Zhang, S.; Shi, C.; McClements, D.J.; Liu, X.; Liu, F. Development of Antibacterial Nanoemulsions Incorporating Thyme Oil: Layer-by-Layer Self-Assembly of Whey Protein Isolate and Chitosan Hydrochloride. *Food Chem.* **2021**, *339*, 128016. [CrossRef]
17. Min, T.; Zhou, L.; Sun, X.; Du, H.; Zhu, Z.; Wen, Y. Electrospun Functional Polymeric Nanofibers for Active Food Packaging: A Review. *Food Chem.* **2022**, *391*, 133239. [CrossRef]
18. Liu, Y.; Wang, S.; Zhang, R.; Lan, W.; Qin, W. Development of Poly(Lactic Acid)/Chitosan Fibers Loaded with Essential Oil for Antimicrobial Applications. *Nanomaterials* **2017**, *7*, 194. [CrossRef]
19. Yildirim-Yalcin, M.; Tornuk, F.; Toker, O.S. Recent Advances in the Improvement of Carboxymethyl Cellulose-Based Edible Films. *Trends Food Sci. Technol.* **2022**, *129*, 179–193. [CrossRef]
20. Dhall, R.K. Advances in Edible Coatings for Fresh Fruits and Vegetables: A Review. *Crit. Rev. Food Sci. Nutr.* **2013**, *53*, 435–450. [CrossRef]
21. Holman, B.W.B.; Kerry, J.P.; Hopkins, D.L. Meat Packaging Solutions to Current Industry Challenges: A Review. *Meat Sci.* **2018**, *144*, 159–168. [CrossRef] [PubMed]
22. Zhang, C.; Li, Y.; Wang, P.; Zhang, H. Electrospinning of Nanofibers: Potentials and Perspectives for Active Food Packaging. *Compr. Rev. Food Sci. Food Saf.* **2020**, *19*, 479–502. [CrossRef] [PubMed]
23. Gagaoua, M.; Pinto, V.Z.; Göksen, G.; Alessandroni, L.; Lamri, M.; Dib, A.L.; Boukid, F. Electrospinning as a Promising Process to Preserve the Quality and Safety of Meat and Meat Products. *Coatings* **2022**, *12*, 644. [CrossRef]
24. Bhargava, N.; Sharanagat, V.S.; Mor, R.S.; Kumar, K. Active and Intelligent Biodegradable Packaging Films Using Food and Food Waste-Derived Bioactive Compounds: A Review. *Trends Food Sci. Technol.* **2020**, *105*, 385–401. [CrossRef]
25. Osmólska, E.; Stoma, M.; Starek-Wójcicka, A. Application of Biosensors, Sensors, and Tags in Intelligent Packaging Used for Food Products—A Review. *Sensors* **2022**, *22*, 9956. [CrossRef]
26. Rehman, A.; Jafari, S.M.; Aadil, R.M.; Assadpour, E.; Randhawa, M.A.; Mahmood, S. Development of Active Food Packaging via Incorporation of Biopolymeric Nanocarriers Containing Essential Oils. *Trends Food Sci. Technol.* **2020**, *101*, 106–121. [CrossRef]
27. Smaoui, S.; Hlima, H.B.; Tavares, L.; Ennouri, K.; Braiek, O.B.; Mellouli, L.; Abdelkafi, S.; Khaneghah, A.M. Application of Essential Oils in Meat Packaging: A Systemic Review of Recent Literature. *Food Control* **2022**, *132*, 108566. [CrossRef]
28. Dai, J.; Hu, W.; Yang, H.; Li, C.; Cui, H.; Li, X.; Lin, L. Controlled Release and Antibacterial Properties of PEO/Casein Nanofibers Loaded with Thymol/β-Cyclodextrin Inclusion Complexes in Beef Preservation. *Food Chem.* **2022**, *382*, 132369. [CrossRef]
29. Raut, J.S.; Karuppayil, S.M. A Status Review on the Medicinal Properties of Essential Oils. *Ind. Crops Prod.* **2014**, *62*, 250–264. [CrossRef]
30. Doğan, C.; Doğan, N.; Gungor, M.; Eticha, A.K.; Akgul, Y. Novel Active Food Packaging Based on Centrifugally Spun Nanofibers Containing Lavender Essential Oil: Rapid Fabrication, Characterization, and Application to Preserve of Minced Lamb Meat. *Food Packag. Shelf Life* **2022**, *34*, 100942. [CrossRef]
31. Said, N.S.; Sarbon, N.M. Response Surface Methodology (RSM) of Chicken Skin Gelatin Based Composite Films with Rice Starch and Curcumin Incorporation. *Polym. Test.* **2020**, *81*, 106161. [CrossRef]
32. Popović, S.Z.; Lazić, V.L.; Hromiš, N.M.; Šuput, D.Z.; Bulut, S.N. Chapter 8—Biopolymer Packaging Materials for Food Shelf-Life Prolongation. In *Biopolymers for Food Design*; Grumezescu, A.M., Holban, A.M., Eds.; Handbook of Food Bioengineering; Academic Press: Cambridge, MA, USA, 2018; pp. 223–277, ISBN 978-0-12-811449-0.

33. Hosseini, S.M.H.; Ghiasi, F.; Jahromi, M. 12—Nanocapsule Formation by Complexation of Biopolymers. In *Nanoencapsulation Technologies for the Food and Nutraceutical Industries*; Jafari, S.M., Ed.; Academic Press: Cambridge, MA, USA, 2017; pp. 447–492, ISBN 978-0-12-809436-5.
34. Shankar, S.; Wang, L.-F.; Rhim, J.-W. Preparation and Properties of Carbohydrate-Based Composite Films Incorporated with CuO Nanoparticles. *Carbohydr. Polym.* **2017**, *169*, 264–271. [CrossRef]
35. Shankar, S.; Tanomrod, N.; Rawdkuen, S.; Rhim, J.-W. Preparation of Pectin/Silver Nanoparticles Composite Films with UV-Light Barrier and Properties. *Int. J. Biol. Macromol.* **2016**, *92*, 842–849. [CrossRef]
36. Babaremu, K.; Oladijo, O.P.; Akinlabi, E. Biopolymers: A Suitable REPLACEMENT for Plastics in Product Packaging. *Adv. Ind. Eng. Polym. Res.* **2023**, *in press*. [CrossRef]
37. Ahmad, A.; Qurashi, A.; Sheehan, D. Nano Packaging—Progress and Future Perspectives for Food Safety, and Sustainability. *Food Packag. Shelf Life* **2023**, *35*, 100997. [CrossRef]
38. Ruan, C.; Zhang, Y.; Wang, J.; Sun, Y.; Gao, X.; Xiong, G.; Liang, J. Preparation and Antioxidant Activity of Sodium Alginate and Carboxymethyl Cellulose Edible Films with Epigallocatechin Gallate. *Int. J. Biol. Macromol.* **2019**, *134*, 1038–1044. [CrossRef]
39. Robertson, G.L. *Food Packaging: Principles and Practice*; CRC Press: Boca Raton, FL, USA, 2016; ISBN 9780429105401. [CrossRef]
40. Liu, Y.; Ahmed, S.; Sameen, D.E.; Wang, Y.; Lu, R.; Dai, J.; Li, S.; Qin, W. A Review of Cellulose and Its Derivatives in Biopolymer-Based for Food Packaging Application. *Trends Food Sci. Technol.* **2021**, *112*, 532–546. [CrossRef]
41. Zhong, Y.; Godwin, P.; Jin, Y.; Xiao, H. Biodegradable Polymers and Green-Based Antimicrobial Packaging Materials: A Mini-Review. *Adv. Ind. Eng. Polym. Res.* **2020**, *3*, 27–35. [CrossRef]
42. Onyeaka, H.; Obileke, K.; Makaka, G.; Nwokolo, N. Current Research and Applications of Starch-Based Biodegradable Films for Food Packaging. *Polymers* **2022**, *14*, 1126. [CrossRef]
43. Su, C.; Li, D.; Wang, L.; Wang, Y. Biodegradation Behavior and Digestive Properties of Starch-Based Film for Food Packaging—A Review. *Crit. Rev. Food Sci. Nutr.* **2022**, 1–23. [CrossRef]
44. Dang, K.M.; Yoksan, R. Morphological Characteristics and Barrier Properties of Thermoplastic Starch/Chitosan Blown Film. *Carbohydr. Polym.* **2016**, *150*, 40–47. [CrossRef] [PubMed]
45. Pelissari, F.M.; Ferreira, D.C.; Louzada, L.B.; dos Santos, F.; Corrêa, A.C.; Moreira, F.K.V.; Mattoso, L.H. Chapter 10—Starch-Based Edible Films and Coatings: An Eco-Friendly Alternative for Food Packaging. In *Starches for Food Application*; Clerici, M.T.P.S., Schmiele, M., Eds.; Academic Press: Cambridge, MA, USA, 2019; pp. 359–420, ISBN 978-0-12-809440-2.
46. Thakur, R.; Pristijono, P.; Scarlett, C.J.; Bowyer, M.; Singh, S.P.; Vuong, Q.V. Starch-Based Films: Major Factors Affecting Their Properties. *Int. J. Biol. Macromol.* **2019**, *132*, 1079–1089. [CrossRef] [PubMed]
47. Wiszumirska, K.; Czarnecka-Komorowska, D.; Kozak, W.; Biegańska, M.; Wojciechowska, P.; Jarzębski, M.; Pawlak-Lemańska, K. Characterization of Biodegradable Food Contact Materials under Gamma-Radiation Treatment. *Materials* **2023**, *16*, 859. [CrossRef] [PubMed]
48. Priyadarshi, R.; Rhim, J.-W. Chitosan-Based Biodegradable Functional Films for Food Packaging Applications. *Innov. Food Sci. Emerg. Technol.* **2020**, *62*, 102346. [CrossRef]
49. Okutan, N.; Terzi, P.; Altay, F. Affecting Parameters on Electrospinning Process and Characterization of Electrospun Gelatin Nanofibers. *Food Hydrocoll.* **2014**, *39*, 19–26. [CrossRef]
50. Etxabide, A.; Akbarinejad, A.; Chan, E.W.C.; Guerrero, P.; de la Caba, K.; Travas-Sejdic, J.; Kilmartin, P.A. Effect of Gelatin Concentration, Ribose and Glycerol Additions on the Electrospinning Process and Physicochemical Properties of Gelatin Nanofibers. *Eur. Polym. J.* **2022**, *180*, 111597. [CrossRef]
51. Krishnakumar, G.S.; Sampath, S.; Muthusamy, S.; John, M.A. Importance of Crosslinking Strategies in Designing Smart Biomaterials for Bone Tissue Engineering: A Systematic Review. *Mater. Sci. Eng. C* **2019**, *96*, 941–954. [CrossRef]
52. Kwak, H.W.; Park, J.; Yun, H.; Jeon, K.; Kang, D.-W. Effect of Crosslinkable Sugar Molecules on the Physico-Chemical and Antioxidant Properties of Fish Gelatin Nanofibers. *Food Hydrocoll.* **2021**, *111*, 106259. [CrossRef]
53. Hanani, Z.A.N.; Roos, Y.H.; Kerry, J.P. Use and Application of Gelatin as Potential Biodegradable Packaging Materials for Food Products. *Int. J. Biol. Macromol.* **2014**, *71*, 94–102. [CrossRef]
54. Kchaou, H.; Benbettaïeb, N.; Jridi, M.; Abdelhedi, O.; Karbowiak, T.; Brachais, C.-H.; Léonard, M.-L.; Debeaufort, F.; Nasri, M. Enhancement of Structural, Functional and Antioxidant Properties of Fish Gelatin Films Using Maillard Reactions. *Food Hydrocoll.* **2018**, *83*, 326–339. [CrossRef]
55. Etxabide, A.; Vairo, C.; Santos-Vizcaino, E.; Guerrero, P.; Pedraz, J.L.; Igartua, M.; de la Caba, K.; Hernandez, R.M. Ultra Thin Hydro-Films Based on Lactose-Crosslinked Fish Gelatin for Wound Healing Applications. *Int. J. Pharm.* **2017**, *530*, 455–467. [CrossRef]
56. Etxabide, A.; Kilmartin, P.A.; Maté, J.I.; Prabakar, S.; Brimble, M.; Naffa, R. Analysis of Advanced Glycation End Products in Ribose-, Glucose- and Lactose-Crosslinked Gelatin to Correlate the Physical Changes Induced by Maillard Reaction in Films. *Food Hydrocoll.* **2021**, *117*, 106736. [CrossRef]
57. Etxabide, A.; Urdanpilleta, M.; Gómez-Arriaran, I.; de la Caba, K.; Guerrero, P. Effect of PH and Lactose on Cross-Linking Extension and Structure of Fish Gelatin Films. *React. Funct. Polym.* **2017**, *117*, 140–146. [CrossRef]
58. Stevenson, M.; Long, J.; Seyfoddin, A.; Guerrero, P.; de la Caba, K.; Etxabide, A. Characterization of Ribose-Induced Crosslinking Extension in Gelatin Films. *Food Hydrocoll.* **2020**, *99*, 105324. [CrossRef]

59. Yaman, M.; Sar, M.; Ceylan, Z. A Nanofiber Application for Thiamine Stability and Enhancement of Bioaccessibility of Raw, Cooked Salmon and Red Meat Samples Stored at 4 °C. *Food Chem.* **2022**, *373*, 131447. [CrossRef]
60. Shaikh, S.; Yaqoob, M.; Aggarwal, P. An Overview of Biodegradable Packaging in Food Industry. *Curr. Res. Food Sci.* **2021**, *4*, 503–520. [CrossRef]
61. Alghoraibi, I.; Alomari, S. Different Methods for Nanofiber Design and Fabrication. In *Handbook of Nanofibers*; Barhoum, A., Bechelany, M., Makhlouf, A., Eds.; Springer International Publishing: Cham, Switzerland, 2018; pp. 1–46, ISBN 978-3-319-42789-8.
62. Xue, J.; Wu, T.; Dai, Y.; Xia, Y. Electrospinning and Electrospun Nanofibers: Methods, Materials, and Applications. *Chem. Rev.* **2019**, *119*, 5298–5415. [CrossRef]
63. Liu, P.; Wu, S.; Zhang, Y.; Zhang, H.; Qin, X. A Fast Response Ammonia Sensor Based on Coaxial PPy–PAN Nanofiber Yarn. *Nanomaterials* **2016**, *6*, 121. [CrossRef]
64. Das, S.K.; Afzal, M.A.F.; Srivastava, S.; Patil, S.; Sharma, A. Enhanced Electrical Conductivity of Suspended Carbon Nanofibers: Effect of Hollow Structure and Improved Graphitization. *Carbon* **2016**, *108*, 135–145. [CrossRef]
65. He, P.; Zhong, Q.; Ge, Y.; Guo, Z.; Tian, J.; Zhou, Y.; Ding, S.; Li, H.; Zhou, C. Dual Drug Loaded Coaxial Electrospun PLGA/PVP Fiber for Guided Tissue Regeneration under Control of Infection. *Mater. Sci. Eng. C* **2018**, *90*, 549–556. [CrossRef]
66. Katsogiannis, K.A.G.; Vladisavljević, G.T.; Georgiadou, S. Porous Electrospun Polycaprolactone (PCL) Fibres by Phase Separation. *Eur. Polym. J.* **2015**, *69*, 284–295. [CrossRef]
67. Thenmozhi, S.; Dharmaraj, N.; Kadirvelu, K.; Kim, H.Y. Electrospun Nanofibers: New Generation Materials for Advanced Applications. *Mater. Sci. Eng. B* **2017**, *217*, 36–48. [CrossRef]
68. Kny, E.; Ghosal, K.; Thomas, S. (Eds.) *Electrospinning: From Basic Research to Commercialization*; Soft Matter Series; The Royal Society of Chemistry: London, UK, 2018; ISBN 978-1-78801-100-6.
69. Göksen, G.; Fabra, M.J.; Pérez-Cataluña, A.; Ekiz, H.I.; Sanchez, G.; López-Rubio, A. Biodegradable Active Food Packaging Structures Based on Hybrid Cross-Linked Electrospun Polyvinyl Alcohol Fibers Containing Essential Oils and Their Application in the Preservation of Chicken Breast Fillets. *Food Packag. Shelf Life* **2021**, *27*, 100613. [CrossRef]
70. Lin, L.; Liao, X.; Cui, H. Cold Plasma Treated Thyme Essential Oil/Silk Fibroin Nanofibers against Salmonella Typhimurium in Poultry Meat. *Food Packag. Shelf Life* **2019**, *21*, 100337. [CrossRef]
71. Surendhiran, D.; Cui, H.; Lin, L. Encapsulation of Phlorotannin in Alginate/PEO Blended Nanofibers to Preserve Chicken Meat from Salmonella Contaminations. *Food Packag. Shelf Life* **2019**, *21*, 100346. [CrossRef]
72. Forghani, S.; Almasi, H.; Moradi, M. Electrospun Nanofibers as Food Freshness and Time-Temperature Indicators: A New Approach in Food Intelligent Packaging. *Innov. Food Sci. Emerg. Technol.* **2021**, *73*, 102804. [CrossRef]
73. Zhang, C.; Li, Y.; Wang, P.; Zhang, A.; Feng, F.; Zhang, H. Electrospinning of Bilayer Emulsions: The Role of Gum Arabic as a Coating Layer in the Gelatin-Stabilized Emulsions. *Food Hydrocoll.* **2019**, *94*, 38–47. [CrossRef]
74. Ge, L.; Zhao, Y.; Mo, T.; Li, J.; Li, P. Immobilization of Glucose Oxidase in Electrospun Nanofibrous Membranes for Food Preservation. *Food Control* **2012**, *26*, 188–193. [CrossRef]
75. Ding, Y.; Wang, Y.; Su, L.; Bellagamba, M.; Zhang, H.; Lei, Y. Electrospun Co3O4 Nanofibers for Sensitive and Selective Glucose Detection. *Biosens. Bioelectron.* **2010**, *26*, 542–548. [CrossRef]
76. Xiong, J.; Shao, W.; Wang, L.; Cui, C.; Jin, Y.; Yu, H.; Han, P.; Gao, Y.; Liu, F.; Ni, Q.; et al. PAN/FPU Composite Nanofiber Membrane with Superhydrophobic and Superoleophobic Surface as a Filter Element for High-Efficiency Protective Masks. *Macromol. Mater. Eng.* **2021**, *306*, 2100371. [CrossRef]
77. Karagoz, S.; Kiremitler, N.B.; Sarp, G.; Pekdemir, S.; Salem, S.; Goksu, A.G.; Onses, M.S.; Sozdutmaz, I.; Sahmetlioglu, E.; Ozkara, E.S.; et al. Antibacterial, Antiviral, and Self-Cleaning Mats with Sensing Capabilities Based on Electrospun Nanofibers Decorated with ZnO Nanorods and Ag Nanoparticles for Protective Clothing Applications. *ACS Appl. Mater. Interfaces* **2021**, *13*, 5678–5690. [CrossRef]
78. Yan, Y.; Liu, X.; Yan, J.; Guan, C.; Wang, J. Electrospun Nanofibers for New Generation Flexible Energy Storage. *ENERGY Environ. Mater.* **2021**, *4*, 502–521. [CrossRef]
79. Lee, M.W.; An, S.; Latthe, S.S.; Lee, C.; Hong, S.; Yoon, S.S. Electrospun Polystyrene Nanofiber Membrane with Superhydrophobicity and Superoleophilicity for Selective Separation of Water and Low Viscous Oil. *ACS Appl. Mater. Interfaces* **2013**, *5*, 10597–10604. [CrossRef]
80. Al-Moghazy, M.; Mahmoud, M.; Nada, A.A. Fabrication of Cellulose-Based Adhesive Composite as an Active Packaging Material to Extend the Shelf Life of Cheese. *Int. J. Biol. Macromol.* **2020**, *160*, 264–275. [CrossRef]
81. Bruni, G.P.; de Oliveira, J.P.; Gómez-Mascaraque, L.G.; Fabra, M.J.; Martins, V.G.; da Rosa Zavareze, E.; López-Rubio, A. Electrospun β-Carotene–Loaded SPI:PVA Fiber Mats Produced by Emulsion-Electrospinning as Bioactive Coatings for Food Packaging. *Food Packag. Shelf Life* **2020**, *23*, 100426. [CrossRef]
82. Zhang, R.; Lan, W.; Ji, T.; Sameen, D.E.; Ahmed, S.; Qin, W.; Liu, Y. Development of Polylactic Acid/ZnO Composite Membranes Prepared by Ultrasonication and Electrospinning for Food Packaging. *LWT* **2021**, *135*, 110072. [CrossRef]
83. Coelho, S.C.; Estevinho, B.N.; Rocha, F. Encapsulation in Food Industry with Emerging Electrohydrodynamic Techniques: Electrospinning and Electrospraying—A Review. *Food Chem.* **2021**, *339*, 127850. [CrossRef]
84. Karim, M.; Fathi, M.; Soleimanian-Zad, S. Nanoencapsulation of Cinnamic Aldehyde Using Zein Nanofibers by Novel Needle-Less Electrospinning: Production, Characterization and Their Application to Reduce Nitrite in Sausages. *J. Food Eng.* **2021**, *288*, 110140. [CrossRef]

85. Luo, X.; Lim, L.-T. Curcumin-Loaded Electrospun Nonwoven as a Colorimetric Indicator for Volatile Amines. *LWT* **2020**, *128*, 109493. [CrossRef]
86. Guo, M.; Wang, H.; Wang, Q.; Chen, M.; Li, L.; Li, X.; Jiang, S. Intelligent Double-Layer Fiber Mats with High Colorimetric Response Sensitivity for Food Freshness Monitoring and Preservation. *Food Hydrocoll.* **2020**, *101*, 105468. [CrossRef]
87. Deng, L.; Zhang, X.; Li, Y.; Que, F.; Kang, X.; Liu, Y.; Feng, F.; Zhang, H. Characterization of Gelatin/Zein Nanofibers by Hybrid Electrospinning. *Food Hydrocoll.* **2018**, *75*, 72–80. [CrossRef]
88. Shekarforoush, E.; Ajalloueian, F.; Zeng, G.; Mendes, A.C.; Chronakis, I.S. Electrospun Xanthan Gum-Chitosan Nanofibers as Delivery Carrier of Hydrophobic Bioactives. *Mater. Lett.* **2018**, *228*, 322–326. [CrossRef]
89. Bhushani, J.A.; Anandharamakrishnan, C. Electrospinning and Electrospraying Techniques: Potential Food Based Applications. *Trends Food Sci. Technol.* **2014**, *38*, 21–33. [CrossRef]
90. Kerr-Phillips, T.; Travas-Sejdic, J. Conducting Polymers: Electrospun Materials. In *Encyclopedia of Polymer Applications*; CRC Press: Boca Raton, FL, USA; Taylor and Francis: New York, NY, USA, 2019; pp. 602–623.
91. Chan, E.W.C.; Bennet, D.; Baek, P.; Barker, D.; Kim, S.; Travas-Sejdic, J. Electrospun Polythiophene Phenylenes for Tissue Engineering. *Biomacromolecules* **2018**, *19*, 1456–1468. [CrossRef] [PubMed]
92. Beikzadeh, S.; Akbarinejad, A.; Swift, S.; Perera, J.; Kilmartin, P.A.; Travas-Sejdic, J. Cellulose Acetate Electrospun Nanofibers Encapsulating Lemon Myrtle Essential Oil as Active Agent with Potent and Sustainable Antimicrobial Activity. *React. Funct. Polym.* **2020**, *157*, 104769. [CrossRef]
93. Contreras, A.; Raxworthy, M.J.; Wood, S.; Tronci, G. Hydrolytic Degradability, Cell Tolerance and On-Demand Antibacterial Effect of Electrospun Photodynamically Active Fibres. *Pharmaceutics* **2020**, *12*, 711. [CrossRef]
94. Hernandez, J.L.; Doan, M.-A.; Stoddard, R.; VanBenschoten, H.M.; Chien, S.-T.; Suydam, I.T.; Woodrow, K.A. Scalable Electrospinning Methods to Produce High Basis Weight and Uniform Drug Eluting Fibrous Biomaterials. *Front. Biomater. Sci.* **2022**, *1*, 1–13. [CrossRef]
95. Lamri, M.; Bhattacharya, T.; Boukid, F.; Chentir, I.; Dib, A.L.; Das, D.; Djenane, D.; Gagaoua, M. Nanotechnology as a Processing and Packaging Tool to Improve Meat Quality and Safety. *Foods* **2021**, *10*, 2633. [CrossRef]
96. Hemmati, F.; Bahrami, A.; Esfanjani, A.F.; Hosseini, H.; McClements, D.J.; Williams, L. Electrospun Antimicrobial Materials: Advanced Packaging Materials for Food Applications. *Trends Food Sci. Technol.* **2021**, *111*, 520–533. [CrossRef]
97. Shepa, I.; Mudra, E.; Dusza, J. Electrospinning through the Prism of Time. *Mater. Today Chem.* **2021**, *21*, 100543. [CrossRef]
98. Kamsani, N.H.; Haris, M.S.; Pandey, M.; Taher, M.; Rullah, K. Biomedical Application of Responsive 'Smart' Electrospun Nanofibers in Drug Delivery System: A Minireview. *Arab. J. Chem.* **2021**, *14*, 103199. [CrossRef]
99. Colino, C.I.; Lanao, J.M.; Gutierrez-Millan, C. Recent Advances in Functionalized Nanomaterials for the Diagnosis and Treatment of Bacterial Infections. *Mater. Sci. Eng. C* **2021**, *121*, 111843. [CrossRef]
100. Arkoun, M.; Daigle, F.; Holley, R.A.; Heuzey, M.C.; Ajji, A. Chitosan-Based Nanofibers as Bioactive Meat Packaging Materials. *Packag. Technol. Sci.* **2018**, *31*, 185–195. [CrossRef]
101. Leidy, R.; Ximena, Q.-C.M. Use of Electrospinning Technique to Produce Nanofibres for Food Industries: A Perspective from Regulations to Characterisations. *Trends Food Sci. Technol.* **2019**, *85*, 92–106. [CrossRef]
102. Yilmaz, M.T.; Hassanein, W.S.; Alkabaa, A.S.; Ceylan, Z. Electrospun Eugenol-Loaded Gelatin Nanofibers as Bioactive Packaging Materials to Preserve Quality Characteristics of Beef. *Food Packag. Shelf Life* **2022**, *34*, 100968. [CrossRef]
103. Moreira, J.B.; de Morais, M.G.; de Morais, E.G.; da Silva Vaz, B.; Costa, J.A.V. Chapter 14—Electrospun Polymeric Nanofibers in Food Packaging. In *Impact of Nanoscience in the Food Industry*; Grumezescu, A.M., Holban, A.M., Eds.; Handbook of Food Bioengineering; Academic Press: Cambridge, MA, USA, 2018; pp. 387–417, ISBN 978-0-12-811441-4.
104. Haghighi, H.; Licciardello, F.; Fava, P.; Siesler, H.W.; Pulvirenti, A. Recent Advances on Chitosan-Based Films for Sustainable Food Packaging Applications. *Food Packag. Shelf Life* **2020**, *26*, 100551. [CrossRef]
105. Sharif, N.; Golmakani, M.-T.; Hajjari, M.M.; Aghaee, E.; Ghasemi, J.B. Antibacterial Cuminaldehyde/Hydroxypropyl-β-Cyclodextrin Inclusion Complex Electrospun Fibers Mat: Fabrication and Characterization. *Food Packag. Shelf Life* **2021**, *29*, 100738. [CrossRef]
106. Yu, Z.; Dhital, R.; Wang, W.; Sun, L.; Zeng, W.; Mustapha, A.; Lin, M. Development of Multifunctional Nanocomposites Containing Cellulose Nanofibrils and Soy Proteins as Food Packaging Materials. *Food Packag. Shelf Life* **2019**, *21*, 100366. [CrossRef]
107. Delosière, M.; Durand, D.; Bourguet, C.; Terlouw, E.M.C. Lipid Oxidation, Pre-Slaughter Animal Stress and Meat Packaging: Can Dietary Supplementation of Vitamin E and Plant Extracts Come to the Rescue? *Food Chem.* **2020**, *309*, 125668. [CrossRef]
108. Khumkomgool, A.; Saneluksana, T.; Harnkarnsujarit, N. Active Meat Packaging from Thermoplastic Cassava Starch Containing Sappan and Cinnamon Herbal Extracts via LLDPE Blown-Film Extrusion. *Food Packag. Shelf Life* **2020**, *26*, 100557. [CrossRef]
109. Panrong, T.; Karbowiak, T.; Harnkarnsujarit, N. Thermoplastic Starch and Green Tea Blends with LLDPE Films for Active Packaging of Meat and Oil-Based Products. *Food Packag. Shelf Life* **2019**, *21*, 100331. [CrossRef]
110. Smaoui, S.; Hlima, H.B.; Tavares, L.; Braïek, O.B.; Ennouri, K.; Abdelkafi, S.; Mellouli, L.; Khaneghah, A.M. Application of Eco-Friendly Active Films and Coatings Based on Natural Antioxidant in Meat Products: A Review. *Prog. Org. Coat.* **2022**, *166*, 106780. [CrossRef]
111. Wen, P.; Wen, Y.; Zong, M.-H.; Linhardt, R.J.; Wu, H. Encapsulation of Bioactive Compound in Electrospun Fibers and Its Potential Application. *J. Agric. Food Chem.* **2017**, *65*, 9161–9179. [CrossRef] [PubMed]

112. Surendhiran, D.; Li, C.; Cui, H.; Lin, L. Fabrication of High Stability Active Nanofibers Encapsulated with Pomegranate Peel Extract Using Chitosan/PEO for Meat Preservation. *Food Packag. Shelf Life* **2020**, *23*, 100439. [CrossRef]
113. Domínguez, R.; Pateiro, M.; Gagaoua, M.; Barba, F.J.; Zhang, W.; Lorenzo, J.M. A Comprehensive Review on Lipid Oxidation in Meat and Meat Products. *Antioxidants* **2019**, *8*, 429. [CrossRef]
114. Domínguez, R.; Barba, F.J.; Gómez, B.; Putnik, P.; Kovačević, D.B.; Pateiro, M.; Santos, E.M.; Lorenzo, J.M. Active Packaging Films with Natural Antioxidants to Be Used in Meat Industry: A Review. *Food Res. Int.* **2018**, *113*, 93–101. [CrossRef]
115. Amna, T.; Yang, J.; Ryu, K.-S.; Hwang, I.H. Electrospun Antimicrobial Hybrid Mats: Innovative Packaging Material for Meat and Meat-Products. *J. Food Sci. Technol.* **2015**, *52*, 4600–4606. [CrossRef]
116. Mihindukulasuriya, S.D.F.; Lim, L.-T. Nanotechnology Development in Food Packaging: A Review. *Trends Food Sci. Technol.* **2014**, *40*, 149–167. [CrossRef]
117. Wang, H.; Kong, L.; Ziegler, G.R. Aligned Wet-Electrospun Starch Fiber Mats. *Food Hydrocoll.* **2019**, *90*, 113–117. [CrossRef]
118. Wang, H.; Kong, L.; Ziegler, G.R. Fabrication of Starch—Nanocellulose Composite Fibers by Electrospinning. *Food Hydrocoll.* **2019**, *90*, 90–98. [CrossRef]
119. Cai, J.; Zhang, D.; Zhou, R.; Zhu, R.; Fei, P.; Zhu, Z.-Z.; Cheng, S.-Y.; Ding, W.-P. Hydrophobic Interface Starch Nanofibrous Film for Food Packaging: From Bioinspired Design to Self-Cleaning Action. *J. Agric. Food Chem.* **2021**, *69*, 5067–5075. [CrossRef]
120. Alehosseini, A.; Gómez-Mascaraque, L.G.; Martínez-Sanz, M.; López-Rubio, A. Electrospun Curcumin-Loaded Protein Nanofiber Mats as Active/Bioactive Coatings for Food Packaging Applications. *Food Hydrocoll.* **2019**, *87*, 758–771. [CrossRef]
121. Yildiz, E.; Sumnu, G.; Kahyaoglu, L.N. Monitoring Freshness of Chicken Breast by Using Natural Halochromic Curcumin Loaded Chitosan/PEO Nanofibers as an Intelligent Package. *Int. J. Biol. Macromol.* **2021**, *170*, 437–446. [CrossRef]
122. Gokoglu, N. Novel Natural Food Preservatives and Applications in Seafood Preservation: A Review. *J. Sci. Food Agric.* **2019**, *99*, 2068–2077. [CrossRef]
123. Karim, M.; Fathi, M.; Soleimanian-Zad, S.; Spigno, G. Development of Sausage Packaging with Zein Nanofibers Containing Tetradecane Produced via Needle-Less Electrospinning Method. *Food Packag. Shelf Life* **2022**, *33*, 100911. [CrossRef]
124. Cheng, S.; Wang, X.; Yang, H.; Lin, R.; Wang, H.; Tan, M. Characterization of Moisture Migration of Beef during Refrigeration Storage by Low-Field NMR and Its Relationship to Beef Quality. *J. Sci. Food Agric.* **2020**, *100*, 1940–1948. [CrossRef]
125. Frank, D.; Zhang, Y.; Li, Y.; Luo, X.; Chen, X.; Kaur, M.; Mellor, G.; Stark, J.; Hughes, J. Shelf Life Extension of Vacuum Packaged Chilled Beef in the Chinese Supply Chain. A Feasibility Study. *Meat Sci.* **2019**, *153*, 135–143. [CrossRef]
126. Madanayake, N.H.; Hossain, A.; Adassooriya, N.M. Nanobiotechnology for Agricultural Sustainability, and Food and Environmental Safety. *Qual. Assur. Saf. Crops Foods* **2021**, *13*, 20–36. [CrossRef]
127. Wang, C.; Chang, T.; Dong, S.; Zhang, D.; Ma, C.; Chen, S.; Li, H. Biopolymer Films Based on Chitosan/Potato Protein/Linseed Oil/ZnO NPs to Maintain the Storage Quality of Raw Meat. *Food Chem.* **2020**, *332*, 127375. [CrossRef]
128. Chen, Y.; Fan, Z.; Zhang, Z.; Niu, W.; Li, C.; Yang, N.; Chen, B.; Zhang, H. Two-Dimensional Metal Nanomaterials: Synthesis, Properties, and Applications. *Chem. Rev.* **2018**, *118*, 6409–6455. [CrossRef]
129. Qiu, M.; Sun, P.; Liu, Y.; Huang, Q.; Zhao, C.; Li, Z.; Mai, W. Visualized UV Photodetectors Based on Prussian Blue/TiO_2 for Smart Irradiation Monitoring Application. *Adv. Mater. Technol.* **2018**, *3*, 1700288. [CrossRef]
130. Xu, X.; Chen, J.; Cai, S.; Long, Z.; Zhang, Y.; Su, L.; He, S.; Tang, C.; Liu, P.; Peng, H.; et al. A Real-Time Wearable UV-Radiation Monitor Based on a High-Performance p-CuZnS/n-TiO_2 Photodetector. *Adv. Mater.* **2018**, *30*, 1803165. [CrossRef] [PubMed]
131. Gu, Z.; Fu, A.; Ye, L.; Kuerban, K.; Wang, Y.; Cao, Z. Ultrasensitive Chemiluminescence Biosensor for Nuclease and Bacterial Determination Based on Hemin-Encapsulated Mesoporous Silica Nanoparticles. *ACS Sens.* **2019**, *4*, 2922–2929. [CrossRef] [PubMed]
132. Hu, J.; Shen, Z.; Tan, L.; Yuan, J.; Gan, N. Electrochemical Aptasensor for Simultaneous Detection of Foodborne Pathogens Based on a Double Stirring Bars-Assisted Signal Amplification Strategy. *Sens. Actuators B Chem.* **2021**, *345*, 130337. [CrossRef]
133. Zhai, X.; Li, Z.; Shi, J.; Huang, X.; Sun, Z.; Zhang, D.; Zou, X.; Sun, Y.; Zhang, J.; Holmes, M.; et al. A Colorimetric Hydrogen Sulfide Sensor Based on Gellan Gum-Silver Nanoparticles Bionanocomposite for Monitoring of Meat Spoilage in Intelligent Packaging. *Food Chem.* **2019**, *290*, 135–143. [CrossRef]
134. Krishnan, S.K.; Singh, E.; Singh, P.; Meyyappan, M.; Nalwa, H.S. A Review on Graphene-Based Nanocomposites for Electrochemical and Fluorescent Biosensors. *RSC Adv.* **2019**, *9*, 8778–8881. [CrossRef]
135. Golmohammadi, H.; Morales-Narváez, E.; Naghdi, T.; Merkoçi, A. Nanocellulose in Sensing and Biosensing. *Chem. Mater.* **2017**, *29*, 5426–5446. [CrossRef]
136. Soares, R.R.A.; Hjort, R.G.; Pola, C.C.; Parate, K.; Reis, E.L.; Soares, N.F.F.; McLamore, E.S.; Claussen, J.C.; Gomes, C.L. Laser-Induced Graphene Electrochemical Immunosensors for Rapid and Label-Free Monitoring of Salmonella Enterica in Chicken Broth. *ACS Sens.* **2020**, *5*, 1900–1911. [CrossRef]
137. Wu, K.-L.; Jiang, B.-B.; Cai, Y.-M.; Wei, X.-W.; Li, X.-Z.; Cheong, W.-C. Efficient Electrocatalyst for Glucose and Ethanol Based on Cu/Ni/N-Doped Graphene Hybrids. *ChemElectroChem* **2017**, *4*, 1419–1428. [CrossRef]
138. Zhou, S.; Zhang, L.; Xie, L.; Zeng, J.; Qiu, B.; Yan, M.; Liang, Q.; Liu, T.; Liang, K.; Chen, P.; et al. Interfacial Super-Assembly of Nanofluidic Heterochannels from Layered Graphene and Alumina Oxide Arrays for Label-Free Histamine-Specific Detection. *Anal. Chem.* **2021**, *93*, 2982–2987. [CrossRef]
139. Minitha, C.R.; Anithaa, V.S.; Subramaniam, V.; Rajendra Kumar, R.T. Impact of Oxygen Functional Groups on Reduced Graphene Oxide-Based Sensors for Ammonia and Toluene Detection at Room Temperature. *ACS Omega* **2018**, *3*, 4105–4112. [CrossRef]

140. Wu, C.; Li, Y.; Sun, J.; Lu, Y.; Tong, C.; Wang, L.; Yan, Z.; Pang, J. Novel Konjac Glucomannan Films with Oxidized Chitin Nanocrystals Immobilized Red Cabbage Anthocyanins for Intelligent Food Packaging. *Food Hydrocoll.* **2020**, *98*, 105245. [CrossRef]
141. Mohammadalinejhad, S.; Almasi, H.; Moradi, M. Immobilization of Echium Amoenum Anthocyanins into Bacterial Cellulose Film: A Novel Colorimetric PH Indicator for Freshness/Spoilage Monitoring of Shrimp. *Food Control* **2020**, *113*, 107169. [CrossRef]
142. Wu, C.; Sun, J.; Chen, M.; Ge, Y.; Ma, J.; Hu, Y.; Pang, J.; Yan, Z. Effect of Oxidized Chitin Nanocrystals and Curcumin into Chitosan Films for Seafood Freshness Monitoring. *Food Hydrocoll.* **2019**, *95*, 308–317. [CrossRef]
143. Alizadeh-Sani, M.; Tavassoli, M.; McClements, D.J.; Hamishehkar, H. Multifunctional Halochromic Packaging Materials: Saffron Petal Anthocyanin Loaded-Chitosan Nanofiber/Methyl Cellulose Matrices. *Food Hydrocoll.* **2021**, *111*, 106237. [CrossRef]
144. Ham, J.; Lim, W.; Whang, K.-Y.; Song, G. Butylated Hydroxytoluene Induces Dysregulation of Calcium Homeostasis and Endoplasmic Reticulum Stress Resulting in Mouse Leydig Cell Death. *Environ. Pollut.* **2020**, *256*, 113421. [CrossRef]
145. Yang, C.; Lim, W.; Bazer, F.W.; Song, G. Propyl Gallate Induces Cell Death and Inhibits Invasion of Human Trophoblasts by Blocking the AKT and Mitogen-Activated Protein Kinase Pathways. *Food Chem. Toxicol.* **2017**, *109*, 497–504. [CrossRef]
146. Domingues, J.M.; Teixeira, M.O.; Teixeira, M.A.; Freitas, D.; da Silva, S.F.; Tohidi, S.D.; Fernandes, R.D.V.; Padrão, J.; Zille, A.; Silva, C.; et al. Inhibition of Escherichia Virus MS2, Surrogate of SARS-CoV-2, via Essential Oils-Loaded Electrospun Fibrous Mats: Increasing the Multifunctionality of Antivirus Protection Masks. *Pharmaceutics* **2022**, *14*, 303. [CrossRef]
147. Aminzare, M.; Hashemi, M.; Ansarian, E.; Bimakr, M.; Hassanzad, A.; Hassan, A. Using Natural Antioxidants in Meat and Meat Products as Preservatives: A Review. *Adv. Anim. Vet. Sci.* **2019**, *7*, 417–426. [CrossRef]
148. Kara, H.H.; Xiao, F.; Sarker, M.; Jin, T.Z.; Sousa, A.M.M.; Liu, C.-K.; Tomasula, P.M.; Liu, L. Antibacterial Poly (Lactic Acid) (PLA) Films Grafted with Electrospun PLA/Allyl Isothiocyanate Fibers for Food Packaging. *J. Appl. Polym. Sci.* **2016**, *133*, 1–8. [CrossRef]
149. Zaitoon, A.; Lim, L.-T.; Scott-Dupree, C. Activated Release of Ethyl Formate Vapor from Its Precursor Encapsulated in Ethyl Cellulose/Poly (Ethylene Oxide) Electrospun Nonwovens Intended for Active Packaging of Fresh Produce. *Food Hydrocoll.* **2021**, *112*, 106313. [CrossRef]
150. Escobar, A.; Pérez, M.; Romanelli, G.; Blustein, G. Thymol Bioactivity: A Review Focusing on Practical Applications. *Arab. J. Chem.* **2020**, *13*, 9243–9269. [CrossRef]
151. Da Silva, B.D.; Bernardes, P.C.; Pinheiro, P.F.; Fantuzzi, E.; Roberto, C.D. Chemical Composition, Extraction Sources and Action Mechanisms of Essential Oils: Natural Preservative and Limitations of Use in Meat Products. *Meat Sci.* **2021**, *176*, 108463. [CrossRef] [PubMed]
152. Lin, L.; Zhu, Y.; Cui, H. Electrospun Thyme Essential Oil/Gelatin Nanofibers for Active Packaging against Campylobacter Jejuni in Chicken. *LWT* **2018**, *97*, 711–718. [CrossRef]
153. Xing, F.; Hua, H.; Selvaraj, J.N.; Zhao, Y.; Zhou, L.; Liu, X.; Liu, Y. Growth Inhibition and Morphological Alterations of Fusarium Verticillioides by Cinnamon Oil and Cinnamaldehyde. *Food Control* **2014**, *46*, 343–350. [CrossRef]
154. Chen, H.; Hu, X.; Chen, E.; Wu, S.; McClements, D.J.; Liu, S.; Li, B.; Li, Y. Preparation, Characterization, and Properties of Chitosan Films with Cinnamaldehyde Nanoemulsions. *Food Hydrocoll.* **2016**, *61*, 662–671. [CrossRef]
155. Stanojević, D.; Comic, L.; Stefanović, O.D.; Solujić-Sukdolak, S. Antimicrobial Effects of Sodium Benzoate, Sodium Nitrite Andpotassium Sorbate and Their Synergistic Action in Vitro. *Bulg. J. Agric. Sci.* **2009**, *15*, 308–312.
156. Mirhadi, E.; Nassirli, H.; Malaekeh-Nikouei, B. An Updated Review on Therapeutic Effects of Nanoparticle-Based Formulations of Saffron Components (Safranal, Crocin, and Crocetin). *J. Pharm. Investig.* **2020**, *50*, 47–58. [CrossRef]
157. Ansarifar, E.; Moradinezhad, F. Encapsulation of Thyme Essential Oil Using Electrospun Zein Fiber for Strawberry Preservation. *Chem. Biol. Technol. Agric.* **2022**, *9*, 2. [CrossRef]
158. Cetinkaya, T.; Mendes, A.C.; Jacobsen, C.; Ceylan, Z.; Chronakis, I.S.; Bean, S.R.; García-Moreno, P.J. Development of Kafirin-Based Nanocapsules by Electrospraying for Encapsulation of Fish Oil. *LWT* **2021**, *136*, 110297. [CrossRef]
159. Najafi, Z.; Cetinkaya, T.; Bildik, F.; Altay, F.; Yeşilçubuk, N.Ş. Nanoencapsulation of Saffron (*Crocus sativus* L.) Extract in Zein Nanofibers and Their Application for the Preservation of Sea Bass Fillets. *LWT* **2022**, *163*, 113588. [CrossRef]
160. Cui, H.; Bai, M.; Li, C.; Liu, R.; Lin, L. Fabrication of Chitosan Nanofibers Containing Tea Tree Oil Liposomes against Salmonella Spp. in Chicken. *LWT* **2018**, *96*, 671–678. [CrossRef]
161. Zhang, J.; Zhang, J.; Huang, X.; Shi, J.; Muhammad, A.; Zhai, X.; Xiao, J.; Li, Z.; Povey, M.; Zou, X. Study on Cinnamon Essential Oil Release Performance Based on PH-Triggered Dynamic Mechanism of Active Packaging for Meat Preservation. *Food Chem.* **2023**, *400*, 134030. [CrossRef]
162. Pavli, F.; Argyri, A.A.; Skandamis, P.; Nychas, G.-J.; Tassou, C.; Chorianopoulos, N. Antimicrobial Activity of Oregano Essential Oil Incorporated in Sodium Alginate Edible Films: Control of Listeria Monocytogenes and Spoilage in Ham Slices Treated with High Pressure Processing. *Materials* **2019**, *12*, 3726. [CrossRef]
163. Arkoun, M.; Daigle, F.; Heuzey, M.-C.; Ajji, A. Mechanism of Action of Electrospun Chitosan-Based Nanofibers against Meat Spoilage and Pathogenic Bacteria. *Molecules* **2017**, *22*, 585. [CrossRef]
164. Zhao, Y.; Teixeira, J.S.; Saldaña, M.D.A.; Gänzle, M.G. Antimicrobial Activity of Bioactive Starch Packaging Films against Listeria Monocytogenes and Reconstituted Meat Microbiota on Ham. *Int. J. Food Microbiol.* **2019**, *305*, 108253. [CrossRef]
165. Lin, L.; Gu, Y.; Cui, H. Novel Electrospun Gelatin-Glycerin-ε-Poly-Lysine Nanofibers for Controlling Listeria Monocytogenes on Beef. *Food Packag. Shelf Life* **2018**, *18*, 21–30. [CrossRef]

166. Li, X.; Xiao, N.; Xiao, G.; Bai, W.; Zhang, X.; Zhao, W. Lemon Essential Oil/Vermiculite Encapsulated in Electrospun Konjac Glucomannan-Grafted-Poly (Acrylic Acid)/Polyvinyl Alcohol Bacteriostatic Pad: Sustained Control Release and Its Application in Food Preservation. *Food Chem.* **2021**, *348*, 129021. [CrossRef]
167. Li, T.; Shen, Y.; Chen, H.; Xu, Y.; Wang, D.; Cui, F.; Han, Y.; Li, J. Antibacterial Properties of Coaxial Spinning Membrane of Methyl Ferulate/Zein and Its Preservation Effect on Sea Bass. *Foods* **2021**, *10*, 2385. [CrossRef]
168. Vargas Romero, E.; Lim, L.-T.; Suárez Mahecha, H.; Bohrer, B.M. The Effect of Electrospun Polycaprolactone Nonwovens Containing Chitosan and Propolis Extracts on Fresh Pork Packaged in Linear Low-Density Polyethylene Films. *Foods* **2021**, *10*, 1110. [CrossRef]
169. Bolumar, T.; LaPeña, D.; Skibsted, L.H.; Orlien, V. Rosemary and Oxygen Scavenger in Active Packaging for Prevention of High-Pressure Induced Lipid Oxidation in Pork Patties. *Food Packag. Shelf Life* **2016**, *7*, 26–33. [CrossRef]
170. Cardoso, G.P.; Dutra, M.P.; Fontes, P.R.; Ramos, A.D.L.S.; de Miranda Gomide, L.A.; Ramos, E.M. Selection of a Chitosan Gelatin-Based Edible Coating for Color Preservation of Beef in Retail Display. *Meat Sci.* **2016**, *114*, 85–94. [CrossRef] [PubMed]
171. Ribeiro-Santos, R.; de Melo, N.R.; Andrade, M.; Azevedo, G.; Machado, A.V.; Carvalho-Costa, D.; Sanches-Silva, A. Whey Protein Active Films Incorporated with a Blend of Essential Oils: Characterization and Effectiveness. *Packag. Technol. Sci.* **2018**, *31*, 27–40. [CrossRef]
172. Borzi, F.; Torrieri, E.; Wrona, M.; Nerín, C. Polyamide Modified with Green Tea Extract for Fresh Minced Meat Active Packaging Applications. *Food Chem.* **2019**, *300*, 125242. [CrossRef]
173. Chaari, M.; Elhadef, K.; Akermi, S.; Ben Akacha, B.; Fourati, M.; Chakchouk Mtibaa, A.; Ennouri, M.; Sarkar, T.; Shariati, M.A.; Rebezov, M.; et al. Novel Active Food Packaging Films Based on Gelatin-Sodium Alginate Containing Beetroot Peel Extract. *Antioxidants* **2022**, *11*, 2095. [CrossRef]
174. Yordshahi, A.S.; Moradi, M.; Tajik, H.; Molaei, R. Design and Preparation of Antimicrobial Meat Wrapping Nanopaper with Bacterial Cellulose and Postbiotics of Lactic Acid Bacteria. *Int. J. Food Microbiol.* **2020**, *321*, 108561. [CrossRef]
175. Behbahani, B.A.; Shahidi, F.; Yazdi, F.T.; Mortazavi, S.A.; Mohebbi, M. Use of Plantago Major Seed Mucilage as a Novel Edible Coating Incorporated with Anethum Graveolens Essential Oil on Shelf Life Extension of Beef in Refrigerated Storage. *Int. J. Biol. Macromol.* **2017**, *94*, 515–526. [CrossRef]
176. Stoleru, E.; Vasile, C.; Irimia, A.; Brebu, M. Towards a Bioactive Food Packaging: Poly (Lactic Acid) Surface Functionalized by Chitosan Coating Embedding Clove and Argan Oils. *Molecules* **2021**, *26*, 4500. [CrossRef]
177. Montaño-Sánchez, E.; Torres-Martínez, B.D.M.; Vargas-Sánchez, R.D.; Huerta-Leidenz, N.; Sánchez-Escalante, A.; Beriain, M.J.; Torrescano-Urrutia, G.R. Effects of Chitosan Coating with Green Tea Aqueous Extract on Lipid Oxidation and Microbial Growth in Pork Chops during Chilled Storage. *Foods Basel Switz.* **2020**, *9*, 766. [CrossRef]
178. Roy, S.; Priyadarshi, R.; Rhim, J.-W. Development of Multifunctional Pullulan/Chitosan-Based Composite Films Reinforced with ZnO Nanoparticles and Propolis for Meat Packaging Applications. *Foods* **2021**, *10*, 2789. [CrossRef]
179. Kaewprachu, P.; Osako, K.; Benjakul, S.; Rawdkuen, S. Quality Attributes of Minced Pork Wrapped with Catechin–Lysozyme Incorporated Gelatin Film. *Food Packag. Shelf Life* **2015**, *3*, 88–96. [CrossRef]
180. Catarino, M.D.; Alves-Silva, J.M.; Fernandes, R.P.; Gonçalves, M.J.; Salgueiro, L.R.; Henriques, M.F.; Cardoso, S.M. 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* **2017**, *80*, 273–280. [CrossRef]
181. Kalem, I.K.; Bhat, Z.F.; Kumar, S.; Noor, S.; Desai, A. The Effects of Bioactive Edible Film Containing Terminalia Arjuna on the Stability of Some Quality Attributes of Chevon Sausages. *Meat Sci.* **2018**, *140*, 38–43. [CrossRef]
182. Shahbazi, Y.; Shavisi, N. A Novel Active Food Packaging Film for Shelf-Life Extension of Minced Beef Meat. *J. Food Saf.* **2018**, *38*, e12569. [CrossRef]
183. Li, L.; Wang, H.; Chen, M.; Jiang, S.; Cheng, J.; Li, X.; Zhang, M.; Jiang, S. Gelatin/Zein Fiber Mats Encapsulated with Resveratrol: Kinetics, Antibacterial Activity and Application for Pork Preservation. *Food Hydrocoll.* **2020**, *101*, 105577. [CrossRef]
184. Duan, M.; Sun, J.; Huang, Y.; Jiang, H.; Hu, Y.; Pang, J.; Wu, C. Electrospun Gelatin/Chitosan Nanofibers Containing Curcumin for Multifunctional Food Packaging. *Food Sci. Hum. Wellness* **2023**, *12*, 614–621. [CrossRef]
185. Radha Krishnan, K.; Babuskin, S.; Rakhavan, K.R.; Tharavin, R.; Azhagu Saravana Babu, P.; Sivarajan, M.; Sukumar, M. Potential Application of Corn Starch Edible Films with Spice Essential Oils for the Shelf Life Extension of Red Meat. *J. Appl. Microbiol.* **2015**, *119*, 1613–1623. [CrossRef]