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Review

The Effects of Processing and Preservation Technologies on Meat Quality: Sensory and Nutritional Aspects

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Abstract: This review describes the effects of processing and preservation technologies on sensory and nutritional quality of meat products. Physical methods such as dry aging, dry curing, high pressure processing (HPP), conventional cooking, sous-vide cooking and 3D printing are discussed. Chemical and biochemical methods as fermentation, smoking, curing, marination, and reformulation are also reviewed. Their technical limitations, due to loss of sensory quality when nutritional value of these products is improved, are presented and discussed. There are several studies focused either on the nutritional or sensorial quality of the processed meat products, but more studies with an integration of the two aspects are necessary. Combination of different processing and preservation methods leads to better results of sensory quality; thus, further research in combinations of different techniques are necessary, such that the nutritional value of meat is not compromised.

Keywords: meat; processing; preservation; sensory quality; nutritional value

1. Introduction

The changes produced in meat due to the application of different processing techniques, preservation methods, and technologies can be basically of two types: physical and chemical. Physical changes are modifications in the structure of the tissues that affect the sensory characteristics of the product such as volume, appearance, color, texture, aroma, and taste. Different effects in meat can be cited; reduced surface moisture due to dehydration, increased moisture and fat retention due to protein denaturation, and enhanced functional properties of proteins due to incorporated additives [1].

The chemical changes in meat are due to the molecular interactions that occur when thermal treatment is applied, food additives are added, or when storage is prolonged. When the chemical structures of the substances responsible for organoleptic characteristics or nutritional value are affected, for instance in the denaturation, hydrolysis, and gelation suffered by proteins due to the actions of boiling water and prolonged heating times [2], the consequences influence the consumer acceptance and affect balanced diet. Technologies which ensure food safety and meet the demands of the consumers without compromising the nutritional value of traditional meat products, are required.

Consumers demand preservative-free, minimally processed meat products with a longer shelf life. Nowadays the use of natural additives instead of synthetic additives is being widely accepted [3]. In addition to this, research on more ecofriendly packaging materials, which improves the shelf life of meat, is gaining momentum. The development of new meat products with improved nutritional profiles has increased over the last decade. For this purpose, there are two main strategies: obtaining healthier fresh meat and post-mortem processing of meat products [4]. These strategies could affect the quality of meat products and their nutritional value.

The meat processing method is usually selected mainly focusing on the technological, microbiological and healthy aspects of the product. However, when selecting a processing and/or preservation technology, not only the quality impact on the product should be considered; a comprehensive and global strategy considering the changes in sensory and nutritional features and consumer appeal is necessary. The objective of this review is to describe the effects of processing and preservation technologies on sensory and nutritional quality of meat products. The technical limitations, which arise due to the loss of sensory quality when nutritional value of these products improved, are presented and discussed. For the purposes of this review, only edible parts of terrestrial animals shall be considered meat.

2. Processing

2.1. Physical Methods

2.1.1. Dry Aging

Dry aging is the process of ripening of meat at controlled conditions. The meat carcasses or primal cuts are hanged in a refrigerated chamber (0–4 °C) with the relative humidity maintained between 75 and 80% for 28–55 days. Until now, only bovine and porcine meats have been investigated. The process is comparably costly due to the need of quality meat cuts, shrinkage loss (6–15%), trim loss (3–4%), and the high risk of open-air contamination in meat. Open-air contamination can be reduced by packaging the meat in highly moisture permeable bags.

The effects of dry aging treatment on meat quality are summarized in Table 1. Dry aged meat has excellent flavor and palatability as a result of proteolysis, lipolysis, and concentration of flavor compounds due to water loss. Dry ageing imparts brown-roasted, beefy, buttery, nutty, roasted-nut, and sweet flavor in bovine meat [5,6]. In beef and pig, dry aged meat has an umami taste due to the high level of glutamate [7,8]. In a comparative study on dry aged and vacuum aged meat, it was observed that the umami and butter fried taste were more prominent in dry aged meat. Moreover, the consumer opinion on sensory aspects of dry aged meat was better in comparison to vacuum aged meat, the meat was found to be more tender and juicier. Dry ageing improves the tenderness and juiciness of bovine and porcine meat [6,7,9].

2.1.2. Dry Curing

Dehydration is the process of reducing the moisture content in meat to improve its shelf life. Automated drying chambers with programmable logic controller and real time monitoring are nowadays widely used in the meat industry. In these chambers the air-flow rate, temperature, relative humidity, and flow distribution can be controlled relative to the size, shape, structure, and moisture content of the product [10]. The water holding capacity, the state of muscle proteins and its microscopic structure determines the rehydration property of the dehydrated meat. The muscle fiber diameter as well as the space between the groups of muscle fibers reduce during dehydration [11]. The rate of reduction in the moisture content during dehydration is high in precooked meat compared to raw meat. The heat damage during dehydration of meat is characterized by the burnt flavor, toughness, and grittiness. The conceptualization of the distribution of water in meat during dehydration can help optimize the process, which can be done by novel non-destructive techniques like hyperspectral imaging. Researchers have used the technique effectively in beef slices where the pixel wise images were taken at different time periods at six specific wavelengths [12]. Regarding the nutritional value of "dehydrated meat", only two studies were carried out, and they were in the 1940s [13,14] (Table 1).

They referred to dehydrated and packaged meat obtained with methods now in disuse. Most countries have their own traditional dried meat products, which have similar sensory features (Table 1). Kilishi is a traditional sun-dried meat product, which is spiced and roasted, with a shelf life of around 12 months. Biltong is another product where meat is salted and dried. Both products are commonly consumed in African countries. Carne do sol and charque are traditional salted dried Brazilian meat products. Tasajo, sou gan, pastirma, and cecina are salted and dried meat products traditionally prepared and consumed in regions like Cuba, China, East Mediterranean, and Mexico/Spain, respectively. Bresaola, jamón serrano, sucuk are traditional salted fermented and dried meat commonly consumed in Italy, Spain, and Turkey [15].

Dried meat products have a hardened texture and wrinkled appearance due to the volume reduction, and sometimes the meat has a hard crust on the surface. Aroma compounds are produced in the meat products as a result of lipid oxidation that imparts a characteristic flavor to the meat [16]. The dried meat has a brown color, the color changes from red to brown according to the temperature. The salt added during drying also adds to the darkening effect. Nitrate/nitrites can also be added to modify the color and flavor of the meat. In dry cured products, the characteristic flavor is due to the metabolites produced as a result of the action of enzymes on meat [16].

2.1.3. High Pressure Processing

High pressure processing (HPP) is a non-thermal decontamination minimal processing technology, where the meat is subjected to a pressure range of 350–600 MPa for a few minutes to acquire improved microbiological safety and shelf life. Pressure is exerted isostatically and the volume of the product decreases with the increase in pressure. HPP can affect the sensory and nutritional characteristics of meat products (Table 1). Application of high pressure breaks the less strong ionic bonds and hydrogen bonds, which in turn denatures the protein via alteration of the quaternary structure of protein followed by tertiary structure at higher pressure ranges. The nutritive value of the meat is minimally affected by HPP [17]. The low molecular weight vitamins and flavor compounds stay intact since pressure does not affect covalent bonds [18]. High pressure treatment can potentially be an effective technology to improve the digestibility of meat products. This effect has been more pronounced in the muscles treated at 600 MPa [19,20].

A pressure higher than 200 MPa leads to the changes in meat protein with various effects of gelation, aggregation, and changes in texture due to the making and breaking of bonds. The effects also vary according to the range of pressure applied and the time of application of the pressure. Meat subjected to high pressure tends to conform to a gel consistency when the secondary and tertiary structure of protein breaks down keeping the primary structure intact. The characteristic structure of myoglobin changes with the application of pressure and it forms a new aggregated protein conformation with reduced solubility [21]. The elasticity of meat increases making it more tender [22]. HPP tends to modify the texture of the meat by tenderizing it, since high pressure fractures rod-like muscles in meat [23]. HPP induces unfolding of myofibrillar proteins, which subsequently exposes sulfhydryl and hydrophobic groups to the surface, unraveling helical structures and forming myosin oligomers through disulfide bond [24].

The meat treated with HPP at high pressure levels of 400 and 600 MPa were associated with browned, livery, and oxidized flavors [25], which will have an impact on the consumer and market behavior of the product. There is no immediate effect of HPP on the oxidative stress of meat [26]. Meat processed at higher pressures for longer period is tougher than the meat processed at a lesser pressure for lesser time [27]. The intrinsic properties of HPP processed meat differs according to the processing conditions applied and the type of raw material. HPP tends to induce aggregation, which improves the digestion of the meat [28]. Some studies did not observe any significant difference in the sensory properties of high pressure processed ready to eat (RTE) meat [29]. When smoked pork rounds were subjected to a pressure of 600 MPa for three minutes significant differences were observed in the cohesiveness and the odor of the meat, whereas the other textural and sensory properties were not affected by the pressure treatment [30].

The HPP treated samples of ham had paler color and softer texture compared to normal ham samples. Some studies concluded that HPP at 500 MPa combined with mild heat treatment at 53 °C was optimal for production of ham [31]. When goose meat was subjected to HPP at an optimal condition of 213 MPa for 15 min, it was observed that pressure range and the time of holding significantly affected the hardness, since the rod like muscles were fractured [23]. High pressure does not have much effect on cooking loss rate or water holding capacity. HPP at 450 MPa and 600 MPa did not significantly change the properties of seared beefsteaks in term of pH, water activity, moisture content, and expressible moisture [27]. However, enhanced water holding capacity was observed in rabbit muscles when subjected to HPP [26].

2.1.4. Conventional Cooking

Cooking makes foods safe to consume and palatable. In order to guarantee food safety, food is cooked at higher temperatures for longer time; however, this practice decreases the nutritional and organoleptic quality of the foods; loss and oxidation of water soluble and thermolabile vitamins, loss of fats due to fusion, chemical browning reactions, etc. [32].

The effects of cooking temperatures on proteins are varied. At temperatures up to 100 °C, as occurs in water or microwave cooking, this denaturation translates into effects of interest, such as enzymatic inactivation of lipases, proteases, etc., improvement of digestibility or reduction of toxicity; between 100 and 140 °C, as in pressure cooking and baking, digestibility is reduced by forming intramolecular and intermolecular covalent bonds [33,34]. The same effects happen at temperatures above 140 °C, as in frying and roasting on the grill, where amino acid destruction occurs, such as cysteine or tryptophan, with isomerization to D-configuration and reduction of nutritional value. In lipids, heat treatment produces fusion, although being triglyceride mixtures it is difficult to establish its exact melting point; before reaching the liquid state, they go through a pasty state, then smoky (at a different temperature depending on the type of fat) and then decompose. Even intense heating can sometimes form toxic cyclic monomers, dimers and polymers, as is the case with acroleins. Carbohydrates are generally considered stable against cooking. However, solubilization losses of these compounds, which depend on factors such as time, size, etc., cannot be avoided [2].

With traditional cooking systems, there is a long waiting time between the preparation and the distribution of meals. Therefore, food must be placed in hot cabinets, ovens, water baths, etc., to avoid its cooling, where the food is dried and over-cooked. The result is a lukewarm meal, with a temperature below 65 °C in the center of the product, and therefore hygienically dangerous as these storage temperatures allow the growth of mesophilic and thermophilic microorganisms that will contaminate dishes during the waiting time for service and consumption. This fact can be dangerous in places of collective catering, such as hospitals, nursing homes, and school canteens, where the group to which the menu is directed has compromised immune system [35].

2.1.5. New Techniques of Cooking: Low-Temperature Long-Time (LTLT) and Sous Vide Cooking

LTLT cooking has numerous advantages, of which the most sought-after characteristics are controlled doneness, improved tenderness and uniform eating quality. In LTLT cooking the product reaches a thermal equilibrium with the medium of heating, which contributes to these additional advantages of the product over traditional high temperature cooking. The underlying mechanism which provides more tender meat (Table 1), regardless of the age of animal, species, or type of muscle, at an optimum combination of temperature and time has not yet been completely elucidated. It might be, possibly, due to the interaction between proteolysis of myofibril structures and heat induced denaturation of proteins. The reduction of LTLT cooking temperature and holding time improve the juiciness of the meat, but at the same time in a constricted temperature range, higher cooking time imparts the desired aroma and flavor characteristics to the cooked meat [36]. The flavor intensity of the LTLT cooked meat is medium to low in comparison with the meat cooked at higher temperature [37,38]. The long cooking time weakens the forces holding the myofibrils together in aged meat leading to meat fragmentation upon shearing [39], and in meat with less amount of connective tissue the degree of tenderization is relatively high when cooked at 50–60 °C [40]. Prolonged heating time denatures the protein even if the temperature of cooking is lower than the actual temperature of denaturation [36].

Sous vide cooking (vacuum cooking) is new variant cooking technique used normally to produce high-quality dishes in the food service sector. Food is vacuum packed in a heat-stable plastic pouch, followed by incubation in a water bath at controlled conditions of time and low temperatures (53–81 °C) [41]. The cooking temperature is maintained lower with a higher cooking time. This technique maintains a uniform meat quality and improves the organoleptic property of the cooked meat. Sous vide cooked meat is more tender and redder than conventionally cooked meat. The duration and the temperature of the cooking comparably affect the physicochemical characteristics and palatability of meat [42].

Some studies have shown that there is significant effect of the cooking time and temperature over the texture of the meat. In sous vide cooked meat the increase of the cooking temperature and time result in increased shear force and toughening, respectively. However, the shear force is reduced when sous vide is combined with other treatments [43]. Water loss in the meat results in shrinkage of the muscular fibers both transversally and longitudinally, aggregation and gelling of sarcoplasmic proteins, shrinkage and solubilization of connective tissues, which leads to the formation of granular fibers. If the sous vide cooking is carried out at higher temperatures the cooking loss is maximum with a minimal reheating loss, due to the increased shrinkage caused by denaturation of the proteins [44]. In some studies of sous vide cooking, an increase of the opacity of meat surface was observed, which was due to the water loss. In sous vide cooked meat the reddish color of meat is replaced by a brownish red with a slight green color since the deoxymyoglobin and oxymyoglobin is denatured with an increase in the metmyoglobin and sulfmyoglobin as a result of longer cooking time [45]. The shelf life of sous vide cooked chicken tikka masala, a traditional Indian meat delicacy was comparatively high (40 days) with slight change in color. The higher shelf life was due to the spices and herbs in the product [46].

Sous vide processing renders meat juicier and more tender and at the same time, the technique improves the digestibility of meat, according to studies conducted on in vitro digestion [47]. However, in a study with young men, no differences were observed between the digestibility of sous vide cooked and fried meat in the pan [48]. Digestibility remains unknown in elderly adults. The volatile profile of sous vide cooked meat is better preserved with little accumulation of off flavor imparting compounds such as hexanal or 3-octanone usually found in traditionally cooked meat. A higher retention of vitamin B_3 is another advantage of sous vide cooking since the cooking temperature is retained at a comparatively lower level [49].

Sous vide cooking can be carried out as low temperature long time or high temperature short time treatments. When the LTLT sous vide cooking method is used, collagen solubilizes, and a larger amount of gelatin is formed with less intense myofibrillar toughening [50]. The high temperature short time alternative can be considered as more economic and feasible method due to the higher safety and comparable quality attributes of the cooked meat, but with a lesser retention of vitamins and higher hardness [49].

Sous vide technique can be combined with other techniques, such as marination. For instance, Gómez et al. [51] reported the feasibility of using the combination of marination and sous vide cooking techniques to yield new RTE meat products with high protein content and without negative characteristics. In this way, the benefits of two different techniques are taken advantage without compromising the quality of the product.

2.1.6. 3D Printing

3D printing is a novel pre-processing technology used in foods, where extrudable food is printed into specific shapes of uniform structure or layers using a 3D printer. There are several categories and ingredients of printable food (Figure 1). 3D printing enables automation, waste reduction, and personalization of foods. Meat should be processed into an extrudable form with added binders or texturizers, such as hydrocolloids or gellable proteins, so that meat can be 3D printed [52,53]. In addition to this, meat should be in a viscoelastic form so that it can be printed into the specific structure [53].

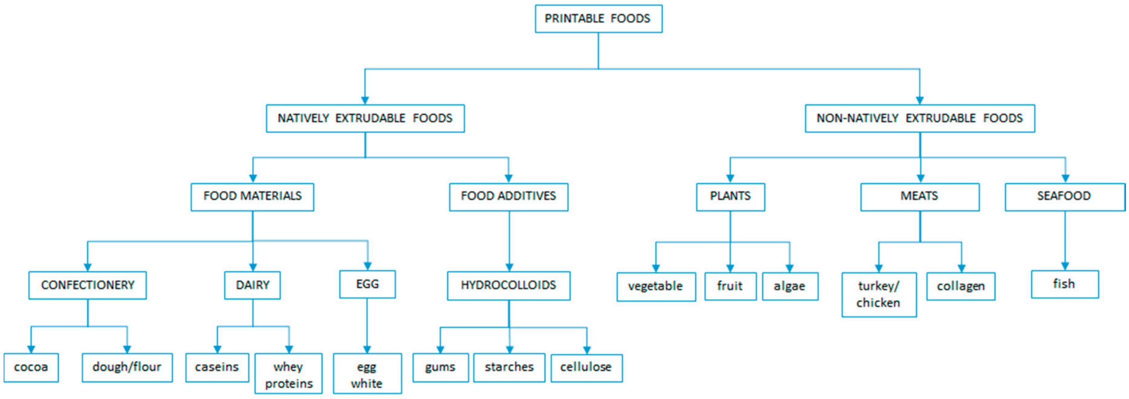

Figure 1. Printable food classification, categories and ingredients.

Few studies have studied the effects of 3D printing on sensory and nutritional characteristics of meat. Turkey puree with added binders and viscosity enhancer was successfully printed for sous vide cooking [54]. Researchers have conducted successful studies on the use of fibrous meat for 3D printing in medical field for elderly and patients who require ketogenic diet [55]. Moreover, beef paste prepared with guar gum binder and lard was 3D printed into multiple layers and sous vide cooked. The cooked samples maintained the structure with slight inward contraction in all the layers. It was observed that increasing the lard layers led to higher cooking loss, shrinkage, cohesiveness, lower fat retention, moisture retention, hardness, and chewiness, whereas increasing the infill density led to higher moisture retention with lower shrinkage and cohesiveness, resulting in higher hardness and chewiness [56].

The state of art in 3D printed meat is such that there are no scientific papers on nutritional and sensory properties, opening a huge opportunity for future research to focus on the same. Moreover post processing of 3D printed foods is required to render it edible, making possible to create a wide range of printed foods [53].

2.2. Chemical and Biochemical Methods

2.2.1. Fermentation

Fermented meat products are mainly dry cured sausages, commonly eaten in many regions worldwide. In the Mediterranean regions, they are medium humidity meat products with considerable shelf life elaborated with spices such as paprika, garlic, and black pepper filled in casings and further cured or ripened so that the flavor would be enhanced. Prior nitrite treatment is considered as a mandatory pretreatment in most of the European countries [57].

The nitrogen compounds in the meat muscles are denatured enzymatically imparting meat the characteristic flavor. The enzymes like protease, aminopeptidases, and microbial enzymes breaks down the proteins in muscles, generating small peptides and amino acids, like alanine, leucine, valine, arginine, lysine, glutamic and aspartic acids, which imparts meat the characteristic flavor. In some cases, the stage of curing is assessed based on the concentration of these amino acids [58–62].

Table 1. Effects of some physical treatments on the sensory and nutritional characteristics of meat products.

Treatment	Meat Product	Effects
Dry aging	Beef meat [5,6,8,9] Porcine meat [7]	More flavor, tenderness and juiciness in beef. Umami taste in beef and porcine meat. Nutritional changes not investigated.
Dry curing	Pork, beef, mutton [13] Meat products [14] Meat products from different animals [15,16]	Increased storage temperature. slightly decreased the digestibility of dried pork protein. Protein quality is not significantly reduced during dehydration. Hardened texture, wrinkled appearance, characteristic flavor, brown color and darkening.
High pressure processing	Beef, pig, chicken meat [17] Different meat products [18] Beef [19] and rabbit [20] muscle Meat products [22] Goose breast [23] Lamb meat cuts [25] Ham [29] Ready to eat (RTE) meat products [30] Pig ham [32]	Unchanged nutritional value. Low molecular weight vitamins and flavor compounds stay intact. Enhanced digestibility. Improved tenderness, changes to the color quality. depending on the content of myoglobin. Improved tenderness. Browned, livery and oxidized flavors. Improved digestibility. No changes in sensory properties. Paler color and softer texture.
Low-temperature long-time (LTLT) and sous vide cooking	Meat [36] Lamb [37] and pork [38] meats Beef [39,40] Chicken meat [42] Beef [45] Pork [47] RTE marinated beef [51]	Increased tenderness and better appearance. Increased flavor. Increased tenderness. Increased tenderness and color. Brownish red with a slight green color. Juicier and more tender meat, and improved digestibility. No effects on sensory characteristics.
3D printing	Turkey and beef meats [54,56]	Novel appearance and texture. Nutritional changes not investigated.

The effects of fermentation on the nutritional and sensory characteristics of meat are listed in Table 2. The flavor and quality of the finished product depends on the process duration. The color is determined by the amount of sarcoplasmic protein. The pH of the product decreases during the fermentation, leading to the gelation of the sarcoplasmic and myofibrillar proteins [63]. *Lactobacillus fermentum* was used as a substitute for nitrite in Harbin red Chinese style sausage, and it was observed that the characteristic pink color of cured meat was retained in the fermented meat [64].

The secondary oxidation products, formed as a part lipolysis and auto-oxidation in the lipids, develop specific aroma compounds like alcohols, aldehydes, ketones, esters, and lactones during the fermentation of the meat [63,65–67]. It has been found that meat proteins can produce bioactive peptides making it more susceptible to be used as functional ingredient too [68].

Presently in the food industry, starter and protective cultures are used, rather than relying on the natural microflora to ensure the sensory and microbial quality of the fermented meat products. During fermentation it has been found that various bacteriocins are produced, which inhibits the growth of other spoilage and pathogenic microorganism [69,70].

2.2.2. Smoking

Smoking is an age-old preservation technique, where meat is subjected to smoke, which affects the sensory and nutritional characteristics of meat products (Table 2). There are positive effects, such as improvement of flavor, color and odor in lamb meat [71]. The effect of smoking on meat increases with the time of exposure [72]. Hot smoking, cold smoking, electrostatic smoking and use of condensates, smoke aromas or liquid smoke are different kinds of smoking treatments. Meat is smoked at 20–25 °C at a relative humidity of 70–80% and at 75–80 °C during cold and hot smoking, respectively. The electrically charged smoke particles which precipitate over the meat in electrostatic smoking reduces the time of processing [73]. In products where the protein denaturation which accompanies the smoking process is deemed undesirable, the smoke aromas or condensates are used [74,75].

Smoke process is an effective treatment against pathogenic microorganisms (*Staphylococcus aureus*, *Escherichia coli*, *Listeria monocytogenes*, *Salmonella* spp., etc.) [76], and reduces the lipid oxidation, which leads to undesirable flavors and oxidative rancidity [77]. In sausages smoking helps to reduce the greyish discoloration [78]. Smoking allows to incorporate different specie meats to obtain a high quality sensory sausages [79]. The sensory scores for smoked buffalo rumen meat products added with ginger extract were found to be within the acceptable limit during the storage period of 15 days [80]. Meat smoking enhances the sensory attributes but at the same time contaminates with carcinogenic residues such as polycyclic aromatic hydrocarbons or nitrosamines [72,81,82]. The residues are nowadays reduced by separating the smoke generating chamber and the smoking chamber, such that the residues precipitate in the generation chamber, exempting the meat of theses harmful residues [73].

Smoking reduces the water activity of meat, which effects the hardness of the product and the protein stability [73]. The digestible indispensable amino acids, which help in evaluating the protein quality in food, were calculated in smoked bacon and improved the content after smoking [83]. Curing combined with smoking has been found to increase the pH and improve the color, texture and odor of buffalo meat [84]. Smoke curing has the combined effect of both enzyme and heat, which leads to alterations in the fatty acid profile of pork and lamb meat [85].

2.2.3. Curing and Salting

The main aim of adding salt into meat was to preserve the meat, but now the cured meats have a high demand due to their characteristic flavor and organoleptic properties. Nitrate and nitrite salts have been known to create the pinkish red color and characteristic flavor of meat and increase their shelf life. Nitrite salts inhibits the lipid oxidation that imparts a rancid flavor to meat [86] (Table 2). Recent studies have found a considerable amount of carcinogenic by-products formed as a result of adding nitrite to meat leading to the reduction in its use for curing [87] opening a window for the use of organically cured meats, where nitrate of natural origin from vegetable sources are used [88,89]. Smoking has been used to improve the preservative effect of meat during curing but nowadays due to the flavor imparted to meat, smoking has developed consumer appeal.

Sodium chloride plays multifunctional role in preservation and processing of meat. It increases the shelf life of cured meat by reducing the water activity of meat, which in turn reduces the microbial load. Salt plays a critical function in determining the gelation, emulsifying and linkage properties in meat muscle proteins [90].

Scientific organizations lately propose the decrease of salt content in processed foods, which has led to a lot of studies on meat with salt replacements, such that the palatability and texture of cured meat are not compromised. Studies on Pamplona chorizo with low salt found that the product was acceptable [91]. The use of potassium chloride, flavor enhancers like carboxymethyl cellulose and carrageenan in combination with sodium citrate [92,93] or combination of sodium, potassium and magnesium salts [94], or undissolved salt crystals were used in various studies to reduce the sodium chloride content in meat with partial success [95], since low salt meat does not have the same palatability as the meat with normal sodium chloride content [96].

2.2.4. Marination

Marination is a meat tenderization procedure, with the use chemical methods. This treatment increases the rate of natural proteolysis in meat, by means of a greater drop in the pH of the meat after slaughter, stimulating the enzymatic proteolytic activity during muscle maturation. Meat is treated with mixtures of different common organic acids like citric acid, acetic acid, and tartaric acid, from orange juice, apple cider vinegar, and agraz-verjus wine (unpublished results). It accelerates the maturation time of the meat by reducing the time necessary for its softening. The mechanism by which marinade influences meat tenderization appears to involve several factors including weakening of structures due to meat swelling, an increase in proteolysis caused by cathepsins, and an increase in the conversion of collagen to gelatin at a low pH during cooking [97].

When a piece of meat is directly immersed in an aqueous solution with various ingredients such as salt, organic acids, etc., the ingredients gradually penetrate by osmosis. The amount of salt and other ingredients from the peripheral parts of the final piece is superior to that of the central zones, not obtaining a homogeneous result [98]. That is why, at an industrial level, marination by immersion is replaced by marinade injection methods [99], which has several effects on the sensory properties of meat on or marinade injection technology in chicken and pork has been developed for years. The poultry industry has used water injection and polyphosphates for more than 20 years [100]; mainly with the aim of facilitating water retention during maturation and subsequent cooking, which leads to an increase in the juiciness of the meat and, with it, an increase in the perception of tenderness by the consumer. Researchers studied the acceptability and shelf life of fresh and precooked pork meat injected with salt, dextrose, citric acid, tripolyphosphate and sodium pyrophosphate, finding that, while citric acid and pyrophosphate lowers the pH of meat, tripolyphosphate increases it, causing a decrease in microbial growth and an improvement in sensory characteristics [101,102]. Researchers also used solutions of salts and phosphate in different cuts of beef, observing an improvement in juiciness and tenderness [103]. Injection at different pressures (345 and 200 kPa) implies differences in losses during cooking and in Warner-Bratzler shear force (WBSF) [104]. However, the softening and increase or enhancement of flavor by immersing the meat in a solution of different tenderizers or flavorings (marinated) has not been widely used in cattle; therefore, its real effectiveness is little known. Different authors have carried out brine injection tests containing, for example, sodium chloride, sodium tripolyphosphate and sodium lactate, finding an increase in juiciness over the control that had not been injected, but without finding significant differences depending on the proportion of injected brine with respect to the initial weight of the meat [105,106]. Other trials have focused on trying to alleviate some adverse effects observed as a result of brine injection, such as color loss or decreased shelf life [107,108].

Table 2. Effects of fermentation, smoking, curing and salting, and marination on the sensory and nutritional characteristics of meat products.

Treatment	Meat Product	Effects
Fermentation	Dry-cured meat products, traditional Jinhua ham, Parma ham, dry-cured Iberian ham [64,66,68]	Specific aroma compounds such as alcohols, aldehydes, ketones, esters and lactones.
	Harbin red Chinese style sausage [64]	The use of *Lactobacillus fermentum* led to characteristic pink color of cured meat.
	Fermented meat products [68]	Production of bioactive peptides.
Smoking	Lamb meat [71]	Enhanced flavor, color and odor.
	Sausage [78]	Reduction of the greyish discoloration.
	Sausages from poultry, pork and beef meat [79]	Enhanced sensory attributes.
	Smoked pork bacon [83]	Improvement of digestibility of indispensable amino acids.
	Buffalo meat [80]	Combination of smoking with curing improved color, texture and odor.
Curing and salting	Bovine muscle [90]	Improved texture properties.
Marination	Broiler chicken [100]	Increase of the juiciness and tenderness.
	Fresh and precooked pork meat [101,102]	
	Beef [103]	Tripolyphosphate in brine improved sensory characteristics.
	Beef [107,108]	Brines of salts and phosphate improved juiciness and tenderness. Color loss.
	Beef [109]	Acid concentrations greater than 0.3 M were not recommended, as they caused great swelling and darkening.
	Beef [110]	The higher acid concentration used for the brine, the greater tenderness. Solution with an acid concentration greater than 0.15 M lead to too acidic beef and rejection by panelists.

Some authors have studied the effect of marinating beef with acidic aqueous solutions. For example, researchers investigated the softening of very fine beef cuts (40 × 35 × 5 mm), obtained from muscles with high connective tissue, from carcasses kept at least 48 h in refrigeration after the slaughter of the animal, and stored under vacuum at −20 °C until use [109]. With these cuts, they carried out immersion tests, for 20 h, in acid solutions prepared from acetic, citric or lactic acids, each one individually, or with mixtures of citrus juices (diluted orange and lemon). The results obtained led them to conclude that acid concentrations greater than 0.3 M were not recommended, as they caused excessive swelling of the meat, as well as its darkening and gelatinization.

Researchers also verified the effect of marinating pieces of neck meat, about 200 g, obtained from beef carcasses that had been maturing four days after the animal was slaughtered [110]. In this case, the marination solutions were prepared with acetic and lactic acids, in concentrations from 0.05 M to 0.25 M. Marination was carried out for two or nine days. Data on the shear resistance force, obtained with a Warner-Bratzler method, indicated that tenderness increased slightly at two days and slightly more at nine days, mainly due to proteolysis. In general, the higher acid concentration used for the marinade, the greater tenderness measured with the Warner-Bratzler method and the greater pH decrease in meat. However, tests carried out with panelists on the same meat indicated that marinating with a solution with an acid concentration greater than 0.15 M was not recommended, since the sensory panelists found the taste excessively acidic and rejected it. Meat with pH values lower than 5.0 was acceptable only up to a point.

2.2.5. Reformulation

Basically two methods are possible to reformulate meat products: the elimination or reduction of components considered harmful to health (fat, saturated fatty acids, salt, nitrites, etc.) and the incorporation or increase of the content of substances with nutritional properties (dietary fiber, proteins of high nutritional value, polyunsaturated fatty acids (PUFA), monounsaturated fatty acids (MUFA), etc.). Table 3 summarizes different examples in which different reformulation alternatives and the consequences on the sensory and nutritional characteristics of foods have been studied.

Reduced Salt Content

The reduction of the salt content unfavorably affects some quality parameters of meat products such as sausages [111], bacon, cooked ham, and salami [112]. In order to minimize the negative effects related to its texture and the interaction of water and fat, binding agents such as phosphates, lactates, chlorides, alginate, and transglutaminase have been used [113], thus preparing various meat products using any of these alternatives (Table 1). The addition of phosphates in low-salt meat products improves the sensory and physico-chemical properties, since it increases the water and fat retention capacity, and reduces the salt content by up to 50% [114]. Gel-forming agents, such as calcium alginate or the enzyme transglutaminase, improves the binding properties and texture. The combination of different sodium, potassium, and magnesium salts have been found to produce meat products with acceptable sensory quality characteristics [114].

Fat Content Modification

The reduction of fat content is generally based on the use of leaner meat or the addition of water and resistant starches, non-starch polysaccharides, gums, or proteins [115]. For the development of low fat products, initial composition, desired final composition (percentage and type of fat) and the type of processing (cooking, curing, smoking, etc.) should be taken into account, since these factors affect the different quality attributes of the final product [114].

The main disadvantages of reducing the fat content in meat products are the loss of juiciness and obtaining a hard and rubbery texture. The solution is the use of different combinations of vegetable fats, proteins, and carbohydrates as fat substitutes, which mimic the mouthfeel and texture of the fat [116].

Reducing fat content in meat products does not reduce cholesterol content, and it has even been suggested that when fat is reduced and lean meat is increased, the cholesterol content of the meat product may increase [114]. Development of meat products with less cholesterol is based on replacing fat and lean meat with vegetable products that do not contain cholesterol, such as vegetable oils and plant proteins [117,118].

Meat products with a more suitable composition can be obtained by modifying the fatty acid profiles by using fats of vegetable and marine origin as partial substitutes for meat fats. In general, vegetable oils are rich in MUFA and PUFA and contain bioactive compounds. The fatty acid composition of the reformulated meat product will be affected by the type of oil used [119]. Various meat products have been elaborated using vegetable oils from olive, sunflower, cottonseed, corn, soybean, flaxseed, rapeseed, peanut, etc., and fish oils (Table 3). Although the replacement of animal fat by vegetable oils improves the lipid profile of the products [1,120,121], the percentage of fat that can be replaced without negative effects needs to be investigated.

Researchers studied the effect of using different proportions of olive and linseed oils for the total or partial substitution of animal fat on beef patties [121]. The best sensory results were obtained in beef patties when 50% of animal fat was replaced by 50% of a mixture of oils (25% olive oil and 75% linseed oil), which in turn gave rise to products with high content of *n*-6 and *n*-3 fatty acids of nutritional interest [121]. Likewise, consumers found no differences in the sensory parameters of these patties, with improved lipid profiles, with respect to the conventional patties [122].

Table 3. Effects of the reformulation of meat products on their sensory and nutritional characteristics.

Compound	Reformulation Objective	Treatment	Meat Product	Effects
Salt	Reduction	Lowering from 2.8% to 0.5%	Hotdog sausages, bacon, ham and salami [112] Pork sausages [126] Chicken breasts [127]: Reconstructed ham [128]	Paler, softer, and less juicy products per low of 1.3–1.7% NaCl. Difficulty reducing the dietary salt intake (<1.4%) without affecting acceptance.
	Partial substitution	Use of spice mixes, KCl or other salts	Cooked ham [92] Bovine and chicken meat [129] Fermented sausages [111,130] Frankfurt sausages [131]	Sensory quality and general acceptability were not modified if replacement ranged 30–35%. Reduced acceptance of aroma, flavor, juiciness and overall quality if NaCl was lower than 1.3%.
Fat	Reduction	Addiction of vegetable oils	Pork sausages [117] Frankfurt sausage [126] Pork sausages [132] Beef and pork sausages [133] Beef patty [134]	Darker, harder, less juicy and less flavor intensity. Better nutritional value (reduction in fat and cholesterol and increase in polyunsaturated fatty acids (PUFA) or monounsaturated fatty acids (MUFA).
	Substitution	Replacing by vegetable or fish oils, soybean proteins, carbohydrates, and synthetic compounds	Sausages, cooked minced meat [116] Veal sausages [118] Bologne sausages [120] Beef patty [121] Spanish salami [135] Sausage [1]	Decrease of meat aroma and flavor intensity. Better nutritional value (reduction in fat and cholesterol and increase in PUFA or MUFA).
	Enhanced nutritional value	Raw material with a high level of mono and polyunsaturated fatty acids from pigs fed with different diets	Dry fermented sausage salchichon [136]	The color was slightly affected. Improved nutritional value.
		Grass-fed or flaxseed-containing concentrates	Beef [137,138]	Improved fatty acid profile by increasing content in conjugated linoleic acid (CLA), eicosapentaenoic acid (EPA) and docosahexaenoic acid DHA.
		Feeding with linseed seeds and CLA	Beef patty [139]	No significant change in color and odor of hamburgers enriched in *n*-3 and CLA. Enhanced lipid profile.
Dietary fiber	Addition of dietary fiber	Addition of dietary fiber (inulin, rice fiber, citrus fiber, etc.)	Sausages [1] Meat products [123] Roast beef [124] Bologne sausages [125,140]	Texture properties decreased (harder and less chewy structures). The 6% inulin concentration provided the best sensory characteristics. Maintained the sensory properties and acceptability. Nutritional value in PUFA improved, the fat content decreased, and the fiber content increased.

Nitrite Content Reduction

In order to inhibit the formation of N-nitrosamines derived from nitrates added to meat products, sodium ascorbate, and erythorbate have been tested, but their effectiveness is limited due to the low solubility in adipose tissue. Studies have been conducted on the addition of fat-soluble derivatives of ascorbic acid, such as L-ascorbyl palmitate and long-chain acetals of ascorbic acid, the combination of α-tocopherol and ascorbate, and the use of lactic acid to inhibit the formation of N-nitrosamines [114].

Until now, a single compound to replace nitrites has been impossible to find, due to the multi-functional role they perform in meat products. Therefore, the solution is to combine several compounds that affect the color, flavor, antioxidant, and antimicrobial activity. Dyes such as erythrosine or the natural coloring pigments formed during external curing ("mononitrosil ferrohemochrome") can be used as alternative methods for maintaining the color of nitrite treated meat. The taste imparted as a result of the added nitrites is due to its antioxidant activity, which is why different antioxidants and chelating chemical agents can be used for its replacement. To replace the antimicrobial effect of nitrites, numerous compounds such as sorbic acid, potassium acid, sodium hypophosphite, fumaric acid esters, parabens, lactic acid producing bacteria, etc. can be used [114].

Incorporation of Protein and Dietary Fiber

Plant proteins are used in meat products to reduce costs, and to improve nutritional benefits [115]. Soybean and sunflower proteins, wheat and corn derivatives, cottonseed, and oatmeal flours have been used as fat substitutes in different meat products such as minced meats, hamburgers and sausages [114]. The functions of plant proteins in meat products are that they act as binders, improve the binding of water and fat and improve the water retention capacity [116]. Soybean protein has been used as a functional ingredient in different meat products like cooked minced meat and sausages [116].

Dietary fiber is incorporated into meat products due its health benefits and due to its ability to improve water and fat retention, increase emulsion stability, increase oxidative stability and modify texture [115,123].

Prebiotics such as inulin, a soluble dietary fiber, and products rich in dietary fiber have been used in the formulation of fresh, cooked, fermented, and crude-cured meat products [1,123–125]. The fiber-rich products that have been added come from many different sources, such as cereals, fruits, dried vegetables, roots, and tubers [115]. Adding dietary fiber improves nutritional properties by decreasing fat content, increasing fiber content, and maintaining sensory features [123].

2.2.6. Enzymes

Enzyme applications include tenderizing meat, restructuring low-value pieces and trimmings of fresh meat for higher-quality products, and improving flavor and aroma. Table 4 summarizes different examples in which they have been used and the effects on the sensory characteristics of meat products.

Enzymes Used for Meat Tenderization

Natural proteolytic enzymes that improve meat tenderness can be from plant, bacterial, or fungal origin. The most widely used plant proteolytic enzymes to improve meat tenderness are papain, bromelain, and ficin [141]. The injection of papain into beef softens the meat, increasing tenderness, maintaining color, and organoleptic characteristics [142]. Injection of beef fillets with a bromelain solution increases tenderness tenderizes meat [143]. Treatment of mortadella with ficin softened the meat without modifying its organoleptic properties of the mortadella [144].

Enzymes Used for Meat Restructuring

Transglutaminase (TGase) improves meat texture characteristics, binding, and performance parameters. TGase can be used in meat emulsions to increase the binding of the solubilized proteins forming a stronger network, increasing the stability of the emulsion [145,146].

Moreover, TGase can bind meat of different shapes and sizes to obtain a uniform restructured meat product such as restructured cooked ham [147], low-salt chicken dumplings [148], chicken doner kebab [149], and restructured pork [150]. The production of restructured meat products with TGase is usually combined with the addition of proteins such as sodium caseinate [151], bisulfite-treated soybeans [152].

Enzymes Used to Produce Flavor and Aromas in Meat

The main enzymatic reactions that affect the flavor and aroma of meat products are proteolysis and lipolysis. These reactions can be carried out by endogenous proteases and lipases, enzymes of microbial origin naturally present in the product, or enzymes added during the manufacturing process [153].

The use of enzymes to improve flavor and aroma has been used mainly in cured meat products. During the maturation of cured meat products, proteolytic enzymes break down proteins and produce nitrogenous compounds and precursors of volatile compounds, which contribute to the development of flavor and aroma [154]. Lipases hydrolyze triacylglycerides into monoacylglycerides, diacylglycerides, and free fatty acids. Free fatty acids are oxidized to volatile aromatic compounds which contribute to the aroma of the final meat product [153].

Table 4. Effects of some enzymatic treatments on the sensory characteristics of meat products.

Objective	Treatment	Meat Product	Effects
Tenderization	Addition of papain, bromelain, ficin,	Beef meat [142] Mortadella [144] Turkey, hen and rooster thighs [157] Beef cubes [158]	Increase of tenderness. Without changes in organoleptic properties.
	Blade tenderization, bromelain or salt/phosphate injection	Muscles from beef rounds [143]	Injection with a salt and phosphate solution resulted in the lowest Warner-Bratzler shear force (WBSF) values. WBSF values for blade tenderization and enzymatic tenderization were comparable.
Restructuring	Addition of transglutaminase (TGase)	Restructured cooked ham [147] Pork gels [159] Low-salt chicken dumplings [148] Chicken sausages [145] Doner kebab of chicken [149] Sausages and ham [146] Restructured pork [150]	No effect on color. Formation of network structures, improving the textural properties: increase of springiness, firmness, decrease in adhesiveness. Increased juiciness, tenderness and overall acceptability. Increase of firmness of meat gels.
	Bisulfite, soybean protein and TGase	Pork sticks [152]	Improvement of tensile strength and cooking performance.
	Sea spaghetti seaweed (3% dry matter) combined with NaCl reduction and a (TGase/caseinate) system	Restructured poultry steaks [151]	Increase in Kramer shear force. Products were acceptable.
Production of flavor and aromas	Addition of palatase M and protease P	Spanish dry fermented sausage (Pamplona chorizo) [155]	Without changes in the sensory quality except a slight softening.
	Intracellular cell free extract (*L lactis* NCDO 763,) and α-ketoglutarate	Dry fermented sausages [156]	Improvement of odor and flavor when *L. lactis* and α-ketoglutarate were combined.

The addition of proteases and lipases in the sausage and chorizo accelerates the proteolysis and lipolysis processes. However, researchers observed no improvement in flavor and aroma, and excessive softening occurred in the chorizo and in some sausages [155]. The addition of an extract of *Lactococcus* *lactis* and α-ketoglutarate in the salami produced an increase in the content of volatile compounds, and improved the sensory properties of the salami, increasing the flavor and aroma of the salami [156].

3. Preservation

3.1. Physical Methods

3.1.1. Thermal Processing

Although cooking technique has been dealt previously in the corresponding processing section, this technique also has an objective in preservation, which is explained below. Pasteurization or sterilization of meat at high temperatures to attain a better shelf life, improved palatability, enhanced flavor is known as thermal processing. The time temperature combinations of thermal processing of meat is generally decided based on the required log reduction of the specific target microorganism, expected shelf life, and the physicochemical properties of meat [160]. The main target microorganism in thermally processed RTE food generally is *Clostridium botulinum*. The target organism in processed meat is *Listeria monocytogenes* since it grows at refrigerated conditions [161]. Cooking, sous vide cooking, canning, retort pouch processing, pasteurization are all different kinds of preservation techniques, which use high temperature to process and preserve meat.

Meat texture varies depending on the internal temperature applied during the processing and on the intrinsic characteristics of meat. The tenderness of meat increases at higher temperatures due to the denaturation of protein, solubilization of collagen, and formation of gelatin [162].

Thermal processing inactivates endogenous proteolytic enzymes and prevents development of off-flavors due to proteolysis. Heat sensitive vitamins are lost during prolonged heating at higher temperatures, but a comparable increase in the shelf life, flavor, and palatability is associated with heat treated foods. Oxidation of sulfhydryl group to disulfide group imparts the cooked flavor to meat. The color of meat changes when meat is subjected to high temperatures since myoglobin gets oxidized, which increases redness and reduces lightness of meat, relating it to the doneness of meat [163]. The consumer preference of the meat varies subjectively but the change in color is accepted as a preferred aspect of cooked meat.

Thermal processing reduces the oxidative stability of meat, which is detrimental to both nutritional and sensory quality of meat, but incorporation of antioxidants into meat has been proven to be a solution for the same [164,165]. Heat treatment has been found to concentrate the micronutrients like zinc, magnesium, iron, phosphorous in meat; however, some amount of these micronutrients are lost to thermal leaching [166].

A lot of studies have been carried out indicating the possibility of a modification of intramuscular fat in meat leading to an increase in the proportion of unsaturated fatty acids and therefore the nutritional value of meat [167–169].

RTE meat products tends to show acceptable sensory characteristics with a slightly reducing trend during storage; but these thermally processed foods in hermetic containers offers a shelf life of over 12 months with slight changes in sensory properties of meat. The sensory attributes like appearance, flavor, texture, juiciness, and overall acceptability of thermally processed traditional Indian meat curry, Rogan josh showed a significant declining trend during its shelf life of 12 months. Rogan josh is a meat product elaborate with thick gravy cooked with big chunks of meat added with spices and condiments, in the aforementioned study beef meat was used. The declining trend was due to the protein degradation and oxidation of the product [160]. Similar results were observed by researchers in RTE retort pouch processed Indian delicacies like Chettinad chicken [170].

3.1.2. Packaging

Packaging options for meat and meat products are air permeable packaging, vacuum packaging, modified atmosphere packaging, active packaging, smart packaging, and edible coatings [171]. Table 5 summarizes different examples of packaging used in meat and meat products and their effects on sensory characteristics.

Vacuum Packing and Modified Atmosphere Packaging

Traditional packaging options for meat and meat products are air-permeable packaging, vacuum packaging, and modified atmosphere packaging. Modified atmosphere packaging improves meat color stability compared to vacuum storage [172], since the maintenance of the bright red color of the meat is possible; however, increased lipid oxidation may occur due to the oxygen content incorporated in the atmosphere. Although vacuum packaging inhibits lipid oxidation, which prevents the development of unpleasant smells and taste [173], the color of the meat becomes purple, which is not the bright red color that consumers associate with fresh meat. Thus, second skin vacuum packaging is considered better than conventional vacuum packaging because it is more visually appealing and has less weight loss [174]. Therefore, the combination of vacuum packaging and modified atmosphere methods can be an efficient way to reduce the negative quality changes that occur when using these systems separately [174].

Active Packaging

Active antioxidant packaging controls the oxygen levels of the packages. There are two active antioxidant packaging systems: separate antioxidant devices and packaging materials with built-in antioxidants [171]. Stand-alone antioxidant devices are sachets, pads, or labels that contain oxygen scavengers. The active agent is incorporated into the walls of the packaging material, so that undesirable compounds are absorbed from the headspace or the antioxidant compounds are released into food [171]. an advantage of incorporating antioxidants in packaging materials, compared to direct addition to food, is controlled release of the active compound.

Antimicrobial agents that have been used in active antimicrobial packaging include plant and spice extracts, essential oils, peptides, organic acids, antibiotics, bacteriocins, and silver ions [163,175,176]. Essential oils have been widely studied as natural antimicrobial agents for meat and meat products, but they produce intense aromas and flavors that affect the sensory quality of meat [177]. Therefore, novel technologies such as the encapsulation of essential oils in nano-emulsions, the incorporation of essential oils in nanorcils and the use of essential oils combined with other antimicrobial methods or agents have been developed. For instance, researchers designed an antimicrobial active packaging system for RTE meat products, consisting of a film of chitosan with thyme essential oil, which improved the color of the meat and prevented the appearance of unpleasant odors [178]. Likewise, the use of chitosan coatings did not influence the sensory characteristics of chicken meatballs and chicken skewers [179] or fresh pork sausages [180].

Intelligent Packaging

The most widely used smart devices in packaging are barcodes, radio frequency identification labels, time–temperature indicators, gas indicators, freshness indicators, and pathogen indicators. Oxygen indicators are the most widely used gas indicator in meat products, since oxygen can cause oxidative rancidity, color changes and development of pathogenic and altering microorganisms [171]. The freshness indicators are based on the detection of freshness indicator metabolites, whose presence causes a color change [181].

This type of smart packaging does not prevent the degradation of the products [182], it only helps to maintain the physical and sensory characteristics, and inhibits degradation resulting from oxidation reactions or product contamination. Therefore, the combination of smart packaging with other technologies is necessary. Researchers studied the combination of smart and active packaging technologies and stated that this combination can be used to assist in the modification of conventional packaging systems in order to enhance product quality and safety [183]. However, further studies would be necessary to assess the impact of the combination of smart packaging technology with other packaging technologies on the organoleptic quality of meat and meat products.

Edible Films and Coatings

The films are made with biopolymers that are based on hydrocolloids such as polysaccharides, proteins of animal origin and proteins of plant origin. Films formed are impervious to moisture and gases but have worse mechanical and functional properties than plastic films [183]. Chitosan is a biopolymer with antioxidant and antimicrobial properties and can be used as a matrix to develop edible films [184]. Edible films and coatings for meat packaging can be combined with the incorporation of active components with antioxidant and antimicrobial properties. The active components that can be incorporated in edible films are natural extracts, essential oils, natural polymers, protein hydrolysates, enzymes, and nanocomponents [185].

Table 5. Effects of different types of packaging on the sensory characteristics of meat products.

Treatment	Meat Product	Effects
Air-permeable packaging, vacuum packaging and modified atmosphere packaging	High pH and normal pH beef [172] Lamb slices [173] Beef steaks [174] Beef fillets [186] Lamb steaks [187] Beef and pork steaks [188] Bison tenderloin steaks [189]	Vacuum packaging inhibits lipid oxidation, thus preventing unpleasant odors and flavors. Packaged in a modified atmosphere with semi-permeable internal vacuum film leads to an attractive bright red color. Packaging in CO_2 improves color and the stability of meat color compared to vacuum package.
Active packaging	Pork patties [190] Beef steaks [191] Beef [175,192]	Active packaging does not affect the tenderness of the meat. Desirable bright red color. Incorporation of essential oils in the active packaging leads to unpleasant flavors and aromas.
Edible films and coatings	Beef [176] Pork meat [193] Minced beef [194] Ready to eat (RTE) meat products [178] Pork meat hamburgers [184] Ground-beef patties [195]	The stability of the red color is improved. Lipid oxidation is inhibited, thus preventing unpleasant odor and flavor.
Combination	Pre-cooked convenience-style foods: battered sausages, bacon slices, and meat and potato pies [196]	Optical oxygen sensors in combined vacuum and modified atmosphere packaged and the use of ethanol emitters: ethanol flavor and aroma were not perceived by panelists in two of the three products assessed.

3.1.3. High Pressure Processing

HPP is also applied for preservation purposes, although HPP has been dealt previously in the corresponding processing section, this section is focused on the conservation approach. Response of vegetative pathogenic and spoilage microorganisms to HPP depends on process parameters such as pressure, temperature, processing time, and on product parameters such as pH, water activity, salt content, and the presence of other antimicrobials. Inactivation of more than four log units of common vegetative pathogenic and spoilage microorganisms can be attained by HPP at 400–600 MPa with short processing times of 3–7 min at room temperature [22].

Ham samples treated by HPP showed increased hardness and syneresis during storage [28]. Ham samples HPP treated at 600 MPa for 5 min showed 2 *log* and 3 *log* reductions of *L. monocytogenes* on the surface and interior respectively. Treatment at 600 MPa for 5 min in completely dry-cured ham reached the food safety objective for *L. monocytogenes*, without significantly affecting the physicochemical characteristics of dry-cured ham [197].

3.2. Chemical and Biochemical Methods

3.2.1. Food Additives

The main additives used in the production of meat derivatives are antioxidants, binders, antimicrobials, curing agents, and curing accelerators.

Synthetic antioxidants approved for use in meat products are butylhydroxyanisole (BHA), butylhydroxytoluene (BHT), propyl gallate, terbutylhydroquinone (TBHQ), and tocopherols. These antioxidants delay or inhibit the oxidation of meat and meat products, and therefore avoid the appearance of unpleasant odors and flavors.

Binder additives are added to the meat to maintain a uniform dispersion of fat throughout the product and to prevent water loss during the different stages of processing, heating, storage, and cooling. The binder additives used in meat and meat products are phosphates, starches, xanthan gum, guar gum, sodium alginate, carrageenan, carboxymethylcellulose, etc. It is worth highlighting the functions of phosphates in meat products, which are to increase the water retention capacity and increase the stabilization of the emulsion. Phosphates also have other functions such as stabilizing color, inhibiting lipid oxidation, and promoting protein dispersion [197].

The synthetic additives used as antimicrobials in meat products are organic acids such as acetic, lactic, propionic, sorbic, benzoic, and citric acids, and sulfites. Sulfites have antimicrobial activity against decomposing microorganisms; however, sulfites cause health problems such as allergic reactions in sensitive people. Organic acids have activity against a wide variety of pathogenic and disrupting microorganisms [198]. Sorbic acid is used in meat products for its inhibitory activity against yeasts and molds. However, it does not affect lactic acid bacteria, which makes it useful as a preservative in fermented meat products [199].

Nitrates and nitrites are the most widely used curing agent in meat products. Nitrites provide the red color and flavor of cured meat, and have antioxidant and antimicrobial properties. The reduction of nitrites and nitrates to nitric oxide is important for the color of cured meat. Nitrosyl myoglobin, which is the dominant pigment in cured meat products, is formed from the interaction of nitric oxide with the *heme* group of myoglobin [200]. Curing accelerators such as sodium ascorbate, sodium erythorbate, ascorbic acid, or erythorbic acid are added to meat to speed up the curing process, as they reduce nitrites to nitric oxide. Nitrites react with amines and amino acids leading to the formation of N-nitrosamines, which are chemical agents with potentially carcinogenic, mutagenic and teratogenic activities. For this reason, alternatives are being sought to reduce or eliminate the addition of nitrites in meat products and reduce health risks [201].

3.2.2. Natural Antioxidant Ingredients

Natural antioxidant ingredients can be used as food additives in meat and meat products for their technological properties. Table 6 summarizes the effect of the addition of natural antioxidants in the formulation of meat and meat products on their sensory characteristics. The antimicrobial and antioxidant activities of some plant extracts and/or their essential oils are mainly due to the presence of some major bioactive compounds, including phenolic acids, terpenes, aldehydes, and flavonoids [202]. It should be highlighted that natural antioxidants can be incorporated into packaging systems, which has been previously explained in the corresponding section.

Essential Oils and Spices

In some cases, the addition of essential oils or spices can have negative effects on meat. For example, the addition of essential oils of oregano and thyme in lamb meat in concentrations greater than 1%, produces a strong odor and unpleasant taste in the product [203]. Adding different extracts like clove or cinnamon to raw chicken can increase L^*, a^*, and b^* values during storage [204]. Cinnamon also increases the redness of meatballs, although it does not affect the other sensory characteristics [205]. The addition of turmeric powder to rabbit patties changed the color of the meat, due to the yellow color of turmeric [206]. Therefore, studies of the concentrations of the added oils and spices, to avoid these negative effects on the sensory characteristics, are required. Adding clove extract to cooked and refrigerated beef patties increased the patties' red color and maintained the sensory characteristics for up to 10 days of storage [207]. Addition of cumin, clove, and cardamom in rista, a traditional Indian sheep meat product cooked with spices, improved the shelf life of the meat product to 25 days with a high overall acceptability score [208].

Plant Extracts

The antioxidant activity of rosemary extract has been evaluated in pork burgers, and it was observed that it did not develop any adverse effects on sensory characteristics or general acceptability of the product [209]. The addition of rosemary (0.25% *v*/*w*) did not negatively influence the taste of turkey meat [210]. The incorporation of oregano extract in sheep burgers did not affect the sensory properties of the burgers [211]. No comparable difference in aroma, flavor, and overall acceptability was observed in low-salt sausages when garlic derivatives were added to it [212].

The addition of green tea extracts to low sulfite beef patties delayed the appearance of rancid flavors, decreased the loss of red color, and did not modify the odor, taste, and texture of the patties [213]. The addition of 250 mg/kg of grape seed extract did not affect sensory characteristics or instrumental color in beef enriched with *n*-3 and CLA [139,214]. However, adding grape seed extracts and green tea could darken pork meatballs [215].

Sensory quality was not negatively altered when blueberries were added to pork burgers and cooked pork ham [216], or when raspberry pomace extracts were added to beef burgers [217], or extract of pomegranate peel and pomegranate juice in cooked chicken patties [3].

The wine pomace, also called grape pomace, a by-product from winery rich in antioxidants [218] is used in the preparation of meat products [219]. For instance, red wine pomace may be an alternative to sulfites as a meat additive for protection of beef patties against protein oxidation [220]. However, the presence of anthocyanins in red grapes has the disadvantage of darkening the product, which could modulate consumer opinion, what must be studied for every type of product. For example, the excess color of seasoned nuggets did not adversely affect the evaluation of other sensory characteristics such as juiciness, crispness, oiliness, saltiness, and chicken flavor [221].

The byproducts of citrus fruit juice processing can be considered as potential ingredients in meat products because of their ability to reduce residual nitrite levels, thus avoiding the possible formation of nitrosamines and nitrosamides. The addition of citrus fiber washing water did not affect the color or texture properties of Bologna sausage, and its combination with rosemary essential oil led to the best sensory quality [222].

Table 6. Effects of the addition of some natural ingredients on the sensory characteristics of meat products.

Natural Ingredients		Meat Product	Effects
Essential oils: thyme, oregano, pimento, clove, citron, lemon verbena, lemon, balm, cypress leaf		Lamb meat [203] Raw chicken [204] Meatballs [205] Beef patties [207]	Extracts like clove or cinnamon increase of *L**, *a** and *b** values during storage. Concentrations of essential oils of oregano and thyme greater than 1% led to strong odor and unpleasant taste. Clove extract increased the *a** values.
Plant extracts: grape seed, green tea, pomegranate peel/rind, acerola, pine bark, bearberry, cinnamon bark, rosemary, garlic, oregano, sansho, ginger, sage.	Grape seed extract (GSE) and wine pomace	Low sulfite beef patties [213] Beef enriched with *n*-3 and CLA [139,214] Pork meatballs [215] Chicken nuggets [221]	GSE showed less color changes during the storage. GSE can darken a meat product. No modification of the sensory attributes except for the color.
	Green tea extract	Low sulphite beef patties [213] Pork meatballs [210]	No effects on odor, taste and texture. Degradation of red color is delayed. No modification of the sensory attributes except for the color.
	Rosemary extract	Turkey meat [210] Pork burgers [209]	No effects on sensory characteristics.
	Oregano extract	Sheep burgers [211]	No effects on sensory characteristics.
	Garlic	Low-salt sausages [212]	No effects on aroma, flavor and overall appearance.
	Other fruit extracts: blueberries, raspberry pomace, pomegranate peel and pomegranate juice	Pork burgers and cooked pork ham [216] Beef burgers [217] Chicken patties [3]	Sensory quality was not negatively altered.
	Citrus fiber	Bologne sausage [222]	No effect on color or texture properties. When citrus fiber is combined with rosemary essential oil, the sensory parameters improved.
Spices		Rabbit burgers [206] Indian sheep meat product [208]	Turmeric powder leads to higher yellow values. Cumin and cardamom led to high overall acceptability score.

4. Conclusions

Numerous techniques have been developed to obtain healthier meat and meat products. However, the modification of the sensory quality should be considered when processing and preservation technologies are applied. Combinations of different technologies are necessary to achieve the best sensory quality in products with improved nutritional profile. In the development of new meat products, a comprehensive approach, including evaluation of sensory characteristics and nutritional value is necessary. Consumers are currently looking for minimally processed products, which are environmentally sustainable. Thus, this review describes the different alternatives, with their advantages and disadvantages, highlighting techniques that improve the sensory characteristics and give rise to products with improved nutritional profile and consumer appeal. Among the processing techniques, physical treatments such as dry aging and HHP stand out as they allow intensifying the flavor and increasing the tenderness of the meat products. Another interesting physical treatment is sous vide cooking, as it is an appropriate technique to preserve nutrients and maintain a high organoleptic quality. Preservation techniques of natural origin stand out as they prolong the shelf life of meat products without negatively affecting the sensory features. The combination of these techniques will make it possible to expand the offer of meat products elaborated with original raw materials, maintaining or even improving their nutritional and sensory characteristics for long periods of time.

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References

1. Beriain, M.J.; Gómez, I.; Petri, E.; Insausti, K.; Sarriés, M.V. The effects of olive oil emulsified alginate on the physico-chemical, sensory, microbial, and fatty acid profiles of low-salt, inulin-enriched sausages. *Meat Sci.* **2011**, *88*, 189–197. [CrossRef] [PubMed]
2. Diéguez, P.M.; Beriain, M.J.; Insausti, K.; Arrizubieta, M.J. Thermal analysis of meat emulsion cooking process by computer simulation and experimental measurement. *Int. J. Food Eng.* **2010**, *6*, 1–21. [CrossRef]
3. Naveena, B.M.; Sen, A.R.; Vaithiyanathan, S.; Babji, Y.; Kondaiah, N. Comparative efficacy of pomegranate juice, pomegranate rind powder extract and BHT as antioxidants in cooked chicken patties. *Meat Sci.* **2008**, *80*, 1304–1308. [CrossRef]
4. Beriain, M.J.; Gómez, I.; Ibanez, F.C.; Sarries, V.; Ordonez, A.I. Improvement of the functional and healthy properties of meat products. In *Food Quality: Balancing Health and Disease*; Grumezescu, A., Holban, A.M., Eds.; Handbook of Food Bioengineering; Academic Press: London, UK, 2018; Volume 13, pp. 1–74. ISBN 978-0-12-811442-1.
5. Warren, K.E.; Kastner, C.L. A comparison of dry-aged and vacuum-aged beef strip loins. *J. Muscle Foods* **1992**, *3*, 151–157. [CrossRef]
6. Campbell, R.E.; Hunt, M.C.; Levis, P.; Chambers, E. Dry-aging effects on palatability of beef longissimus muscle. *J. Food Sci.* **2001**, *66*, 196–199. [CrossRef]
7. Hwang, Y.H.; Sabikun, N.; Ismail, I.; Joo, S.T. Changes in sensory compounds during dry aging of pork cuts. *Food Sci. Anim. Resour.* **2019**, *39*, 379–387. [CrossRef]
8. Kim, Y.H.B.; Kemp, R.; Samuelsson, L.M. Effects of dry-aging on meat quality attributes and metabolite profiles of beef loins. *Meat Sci.* **2016**, *111*, 168–176. [CrossRef]
9. Li, X.; Babol, J.; Bredie, W.L.P.; Nielsen, B.; Tománková, J.; Lundström, K. A comparative study of beef quality after ageing longissimus muscle using a dry ageing bag, traditional dry ageing or vacuum package ageing. *Meat Sci.* **2014**, *97*, 433–442. [CrossRef]
10. Li, J.; Li, Z.; Wang, N.; Raghavan, G.S.V.; Pei, Y.; Song, C.; Zhu, G. Novel sensing technologies during the food drying process. *Food Eng. Rev.* **2020**, *12*, 121–148. [CrossRef]
11. Wang, H.; Doty, D.M.; Beard, F.J.; Pierce, J.C.; Hankins, O.G. Extensibility of single beef muscle fibers. *J. Anim. Sci.* **1956**, *15*, 97–108. [CrossRef]
12. Wu, D.; Wang, S.; Wang, N.; Nie, P.; He, Y.; Sun, D.W.; Yao, J. Application of time series hyperspectral imaging (TS-HSI) for determining water distribution within beef and spectral kinetic analysis during dehydration. *Food Bioprocess. Technol.* **2013**, *6*, 2943–2958. [CrossRef]
13. Hoagland, R.; Snider, G.G. Nutritive value of protein in dehydrated meat. *Food Res.* **1946**, *11*, 494–500. [CrossRef] [PubMed]
14. Rice, E.E.; Robinson, H.E. Nutritive value of canned and dehydrated meat and meat products. *Am. J. Public Health Nations Health* **1944**, *34*, 587–592. [CrossRef] [PubMed]
15. Santchurn, S.J.; Arnaud, E.; Zakhia-Rozis, N.; Collignan, A.; Hui, H.Y. Drying: Principles and applications. In *Handbook of Meat and Meat Processing*; CRC Press: Boca Raton, FL, USA, 2012; pp. 505–521.

16. Flores, M. Understanding the implications of current health trends on the aroma of wet and dry cured meat products. *Meat Sci.* **2018**, *144*, 53–61. [CrossRef] [PubMed]
17. Chen, X.; Tume, R.K.; Xiong, Y.; Xu, X.; Zhou, G.; Chen, C.; Nishiumi, T. Structural modification of myofibrillar proteins by high-pressure processing for functionally improved, value-added, and healthy muscle gelled foods. *Crit. Rev. Food Sci. Nutr.* **2018**, *58*, 2981–3003. [CrossRef] [PubMed]
18. Rastogi, N.K.; Raghavarao, K.S.M.S.; Niranjan, K. Opportunities and challenges in high pressure processing of foods. *Crit. Rev. Food Sci. Nutr.* **2007**, *47*, 69–112. [CrossRef] [PubMed]
19. Kaur, L.; Astruc, T.; Vénien, A.; Loison, O.; Cui, J.; Irastorza, M.; Boland, M. High pressure processing of meat: Effects on ultrastructure and protein digestibility. *Food Funct.* **2016**, *7*, 2389–2397. [CrossRef]
20. Xue, S.; Wang, C.; Kim, Y.H.B.; Bian, G.; Han, M.; Xu, X.; Zhou, G. Application of high-pressure treatment improves the in vitro protein digestibility of gel-based meat product. *Food Chem.* **2020**, *306*, 125602. [CrossRef]
21. Orlien, V. High pressure treatment and the effects on meat proteins. *Med. Res. Arch.* **2017**, *5*, 1–10.
22. Bajovic, B.; Bolumar, T.; Heinz, V. Quality considerations with high pressure processing of fresh and value added meat products. *Meat Sci.* **2012**, *92*, 280–289. [CrossRef]
23. Gao, H.; Zeng, J.; Ma, H.; Wang, Z.; Pan, R. Improving tenderness of goose breast by ultra-high pressure. *Int. J. Food Prop.* **2015**, *18*, 1693–1701. [CrossRef]
24. Chen, X.; Xu, X.; Han, M.; Zhou, G.; Chen, C.; Li, P. Conformational changes induced by high-pressure homogenization inhibit myosin filament formation in low ionic strength solutions. *Food Res. Int.* **2016**, *85*, 1–9. [CrossRef] [PubMed]
25. Ma, Q.; Hamid, N.; Oey, I.; Kantono, K.; Farouk, M. The impact of high-pressure processing on physicochemical properties and sensory characteristics of three different lamb meat cuts. *Molecules* **2020**, *25*, 2665. [CrossRef] [PubMed]
26. Rakotondramavo, A.; Ribourg, L.; Meynier, A.; Guyon, C.; de Lamballerie, M.; Pottier, L. Monitoring oxidation during the storage of pressure-treated cooked ham and impact on technological attributes. *Heliyon* **2019**, *5*, e02285. [CrossRef]
27. Sun, S.; Sullivan, G.; Stratton, J.; Bower, C.; Cavender, G. Effect of HPP treatment on the safety and quality of beef steak intended for sous vide cooking. *LWT Food Sci. Technol.* **2017**, *86*, 185–192. [CrossRef]
28. Rakotondramavo, A.; Rabesona, H.; Brou, C.; de Lamballerie, M.; Pottier, L. Ham processing: Effects of tumbling, cooking and high pressure on proteins. *Eur. Food Res. Technol.* **2019**, *245*, 273–284. [CrossRef]
29. Hayman, M.M.; Baxter, I.; O'Riordan, P.J.; Stewart, C.M. Effects of high-pressure processing on the safety, quality, and shelf life of ready-to-eat meats. *J. Food Prot.* **2004**, *67*, 1709–1718. [CrossRef]
30. Yeh, Y.; Thippareddi, H.; De Mello, A. High pressure processing (HPP) does not affect texture and sensory attributes of smoked hams cured by conventional and alternative methods. *Meat Muscle Biol.* **2017**, *1*, 29. [CrossRef]
31. Pingen, S.; Sudhaus, N.; Becker, A.; Krischek, C.; Klein, G. High pressure as an alternative processing step for ham production. *Meat Sci.* **2016**, *118*, 22–27. [CrossRef]
32. Xiong, Y.L. The storage and preservation of meat: I—Thermal technologies. In *Lawrie's Meat Science*, 8th ed.; Toldrá, F., Ed.; Woodhead Publishing Series in Food Science, Technology and Nutrition; Woodhead Publishing: Cambridge, UK, 2017; pp. 205–230. ISBN 978-0-08-100694-8.
33. Murphy, R.Y.; Marks, B.P.; Marcy, J.A. Apparent specific heat of chicken breast patties and their constituent proteins by differential scanning calorimetry. *J. Food Sci.* **1998**, *63*, 88–91. [CrossRef]
34. Ngadi, M.O.; Ikediala, J.N. Heat transfer properties of chicken-drum muscle. *J. Sci. Food Agric.* **1998**, *78*, 12–18. [CrossRef]
35. Beriain, M.J.; Ibáñez, F.C.; Baleztena, J.; Oria, E. The effect of a modified meat product on nutritional status in institutionalized elderly people. *Nutr. Hosp.* **2011**, *26*, 907–915. [PubMed]
36. Dominguez-Hernandez, E.; Salaseviciene, A.; Ertbjerg, P. Low-temperature long-time cooking of meat: Eating quality and underlying mechanisms. *Meat Sci.* **2018**, *143*, 104–113. [CrossRef] [PubMed]
37. Roldán, M.; Ruiz, J.; del Pulgar, J.S.; Pérez-Palacios, T.; Antequera, T. Volatile compound profile of sous-vide cooked lamb loins at different temperature–time combinations. *Meat Sci.* **2015**, *100*, 52–57. [CrossRef] [PubMed]
38. Sánchez del Pulgar, J.; Roldan, M.; Ruiz-Carrascal, J. Volatile compounds profile of sous-vide cooked pork cheeks as affected by cooking conditions (vacuum packaging, temperature and time). *Molecules* **2013**, *18*, 12538–12547. [CrossRef]

39. Davey, C.L.; Niederer, A.F.; Graafhuis, A.E. Effects of ageing and cooking on the tenderness of beef muscle. *J. Sci. Food Agric.* **1976**, *27*, 251–256. [CrossRef]
40. Davey, C.L.; Niederer, A.F. Cooking tenderizing in beef. *Meat Sci.* **1977**, *1*, 271–276. [CrossRef]
41. Schellekens, M. New research issues in sous-vide cooking. *Trends Food Sci. Technol.* **1996**, *7*, 256–262. [CrossRef]
42. Park, C.H.; Lee, B.; Oh, E.; Kim, Y.S.; Choi, Y.M. Combined effects of sous-vide cooking conditions on meat and sensory quality characteristics of chicken breast meat. *Poult. Sci.* **2020**, *99*, 3286–3291. [CrossRef]
43. Botinestean, C.; Keenan, D.F.; Kerry, J.P.; Hamill, R.M. The effect of thermal treatments including sous-vide, blast freezing and their combinations on beef tenderness of *M. semitendinosus* steaks targeted at elderly consumers. *LWT Food Sci. Technol.* **2016**, *74*, 154–159. [CrossRef]
44. Supaphon, P.; Astruc, T.; Kerdpiboon, S. Physical characteristics and surface-physical properties relationship of Thai local beef during sous-vide processing. *Agric. Nat. Resour.* **2020**, *54*, 25–32. [CrossRef]
45. García-Segovia, P.; Andrés-Bello, A.; Martínez-Monzó, J. Effect of cooking method on mechanical properties, color and structure of beef muscle (M. *pectoralis). J. Food Eng.* **2007**, *80*, 813–821. [CrossRef]
46. Armstrong, G.A.; McIlveen, H. Effects of prolonged storage on the sensory quality and consumer acceptance of sous vide meat-based recipe dishes. *Food Qual. Prefer.* **2000**, *11*, 377–385. [CrossRef]
47. Kehlet, U.; Mitra, B.; Ruiz Carrascal, J.; Raben, A.; Aaslyng, M.D. The satiating properties of pork are not affected by cooking methods, sousvide holding time or mincing in healthy men—A randomized cross-over meal test study. *Nutrients* **2017**, *9*, 941. [CrossRef]
48. Prodhan, U.K.; Pundir, S.; Chiang, V.S.C.; Milan, A.M.; Barnett, M.P.G.; Smith, G.C.; Markworth, J.F.; Knowles, S.O.; Cameron-Smith, D. Comparable postprandial amino acid and gastrointestinal hormone responses to beef steak cooked using different methods: A randomised crossover trial. *Nutrients* **2020**, *12*, 380. [CrossRef] [PubMed]
49. Rinaldi, M.; Dall'Asta, C.; Paciulli, M.; Cirlini, M.; Manzi, C.; Chiavaro, E. A novel time/temperature approach to sous vide cooking of beef muscle. *Food Bioprocess. Technol.* **2014**, *7*, 2969–2977. [CrossRef]
50. Sánchez del Pulgar, J.; Gázquez, A.; Ruiz-Carrascal, J. Physico-chemical, textural and structural characteristics of sous-vide cooked pork cheeks as affected by vacuum, cooking temperature, and cooking time. *Meat Sci.* **2012**, *90*, 828–835. [CrossRef]
51. Gómez, I.; Ibañez, F.C.; Beriain, M.J. Physicochemical and sensory properties of sous vide meat and meat analog products marinated and cooked at different temperature-time combinations. *Int. J. Food Prop.* **2019**, *22*, 1693–1708. [CrossRef]
52. Voon, S.L.; An, J.; Wong, G.; Zhang, Y.; Chua, C.K. 3D food printing: A categorised review of inks and their development. *Virtual Phys. Prototyp.* **2019**, *14*, 203–218. [CrossRef]
53. Portanguen, S.; Tournayre, P.; Sicard, J.; Astruc, T.; Mirade, P.S. Toward the design of functional foods and biobased products by 3D printing: A review. *Trends Food Sci. Technol.* **2019**, *86*, 188–198. [CrossRef]
54. Lipton, J.; Arnold, D.; Nigl, F.; Lopez, N.; Cohen, D.; Norén, N.; Lipson, H. Multi-material food printing with complex internal structure suitable for conventional post-processing. In Proceedings of the Solid Freeform Fabrication Symposium, Austin, TX, USA, 2010; pp. 809–815.
55. Liu, C.; Ho, C.; Wang, J. The development of 3D food printer for printing fibrous meat materials. *IOP Conf. Ser. Mater. Sci. Eng.* **2018**, *284*, 012019. [CrossRef]
56. Dick, A.; Bhandari, B.; Prakash, S. Post-processing feasibility of composite-layer 3D printed beef. *Meat Sci.* **2019**, *153*, 9–18. [CrossRef] [PubMed]
57. Leroy, F.; De Vuyst, L. Fermented foods: Fermented meat products. In *Encyclopedia of Food and Health*; Caballero, B., Finglas, P.M., Toldrá, F., Eds.; Academic Press: Oxford, UK, 2016; pp. 656–660. ISBN 978-0-12-384953-3.
58. Dierick, N.; Vandekerckhove, P.; Demeyer, O. Changes in nonprotein nitrogen compounds during dry sausage ripening. *J. Food Sci.* **1974**, *39*, 301–304. [CrossRef]
59. DeMasi, T.W.; Wardlaw, F.B.; Dick, R.L.; Acton, J.C. Nonprotein nitrogen (NPN) and free amino acid contents of dry, fermented and nonfermented sausages. *Meat Sci.* **1990**, *27*, 1–12. [CrossRef]
60. García de Fernando, G.D.; Fox, P.F. Study of proteolysis during the processing of a dry fermented pork sausage. *Meat Sci.* **1991**, *30*, 367–383. [CrossRef]
61. Beriain, M.J.; Lizaso, G.; Chasco, J. Free amino acids and proteolysis involved in 'salchichon' processing. *Food Control.* **2000**, *11*, 41–47. [CrossRef]

62. Toldrá, F.; Aristoy, M.C.; Part, C.; Cerveró, C.; Rico, E.; Motilva, M.J.; Flores, J. Muscle and adipose tissue aminopeptidase activities in raw and dry-cured ham. *J. Food Sci.* **1992**, *57*, 816–818. [CrossRef]
63. Toldrá, F. The role of muscle enzymes in dry-cured meat products with different drying conditions. *Trends Food Sci. Technol.* **2006**, *17*, 164–168. [CrossRef]
64. Zhang, X.; Kong, B.; Xiong, Y.L. Production of cured meat color in nitrite-free Harbin red sausage by *Lactobacillus fermentum* fermentation. *Meat Sci.* **2007**, *77*, 593–598. [CrossRef]
65. Zhou, G.H.; Zhao, G.M. Biochemical changes during processing of traditional Jinhua ham. *Meat Sci.* **2007**, *77*, 114–120. [CrossRef]
66. Bolzoni, L.; Barbieri, G.; Virgili, R. Changes in volatile compounds of Parma ham during maturation. *Meat Sci.* **1996**, *43*, 301–310. [CrossRef]
67. Ruiz, J.; Ventanas, J.; Cava, R.; Andrés, A.; García, C. Volatile compounds of dry-cured Iberian ham as affected by the length of the curing process. *Meat Sci.* **1999**, *52*, 19–27. [CrossRef]
68. Puchalska, P.; Alegre, M.L.M.; López, M.C.G. Isolation and characterization of peptides with antihypertensive activity in foodstuffs. *Crit. Rev. Food Sci. Nutr.* **2015**, *55*, 521–551. [CrossRef] [PubMed]
69. Cintas, L.M.; Rodriguez, J.M.; Fernandez, M.F.; Sletten, K.; Nes, I.F.; Hernandez, P.E.; Holo, H. Isolation and characterization of pediocin L50, a new bacteriocin from *Pediococcus acidilactici* with a broad inhibitory spectrum. *Appl. Env. Microbiol.* **1995**, *61*, 2643–2648. [CrossRef] [PubMed]
70. Drider, D.; Fimland, G.; Héchard, Y.; McMullen, L.M.; Prévost, H. The continuing story of class IIa bacteriocins. *Microbiol. Mol. Biol. Rev.* **2006**, *70*, 564–582. [CrossRef]
71. Suleman, R.; Wang, Z.; Aadil, R.M.; Hui, T.; Hopkins, D.L.; Zhang, D. Effect of cooking on the nutritive quality, sensory properties and safety of lamb meat: Current challenges and future prospects. *Meat Sci.* **2020**, *167*, 108172. [CrossRef]
72. Pöhlmann, M.; Hitzel, A.; Schwägele, F.; Speer, K.; Jira, W. Influence of different smoke generation methods on the contents of polycyclic aromatic hydrocarbons (PAH) and phenolic substances in Frankfurter-type sausages. *Food Control.* **2013**, *34*, 347–355. [CrossRef]
73. Toldrá, F.; Hui, Y.H. *Handbook of Fermented Meat and Poultry*, 1st ed.; Toldrá, F., Hui, Y.H., Eds.; Blackwell Publishing Ltd.: Ames, AI, USA, 2007; ISBN 978-0-8138-1477-3.
74. Bertram, H.C.; Kohler, A.; Böcker, U.; Ofstad, R.; Andersen, H.J. Heat-induced changes in myofibrillar protein structures and myowater of two pork qualities. A combined FT-IR spectroscopy and low-field NMR relaxometry study. *J. Agric. Food Chem.* **2006**, *54*, 1740–1746. [CrossRef]
75. Stabursvik, E.; Martens, H. Thermal denaturation of proteins in post rigor muscle tissue as studied by differential scanning calorimetry. *J. Sci. Food Agric.* **1980**, *31*, 1034–1042. [CrossRef]
76. Lingbeck, J.M.; Cordero, P.; O'Bryan, C.A.; Johnson, M.G.; Ricke, S.C.; Crandall, P.G. Functionality of liquid smoke as an all-natural antimicrobial in food preservation. *Meat Sci.* **2014**, *97*, 197–206. [CrossRef]
77. Estrada-Muñoz, R.; Boyle, E.a.E.; Marsden, J.L. Liquid smoke effects on *Escherichia coli* O157:H7, and its antioxidant properties in beef products. *J. Food Sci.* **1998**, *63*, 150–153. [CrossRef]
78. Incze, K. European products. In *Handbook of Fermented Meat and Poultry*; Toldrá, F., Ed.; Blackwell Publishing Ltd.: Oxford, UK, 2007; pp. 307–318. ISBN 978-0-470-37643-0.
79. Jantawat, P.; Carpenter, J.A. Salt preblending and incorporation of mechanically deboned chicken meat in smoked sausage. *J. Food Qual.* **1989**, *12*, 393–401. [CrossRef]
80. Anandh, M.A.; Lakshmanan, V. Storage stability of smoked buffalo rumen meat product treated with ginger extract. *J. Food Sci. Technol.* **2014**, *51*, 1191–1196. [CrossRef] [PubMed]
81. Hou, C.; Wang, Z.; Wu, L.; Chai, J.; Song, X.; Wang, W.; Zhang, D. Effects of breeds on the formation of heterocyclic aromatic amines in smoked lamb. *Int. J. Food Sci. Technol.* **2017**, *52*, 2661–2669. [CrossRef]
82. Sugimura, T.; Wakabayashi, K.; Nakagama, H.; Nagao, M. Heterocyclic amines: Mutagens/carcinogens produced during cooking of meat and fish. *Cancer Sci.* **2004**, *95*, 290–299. [CrossRef]
83. Bailey, H.M.; Berg, E.P.; Stein, H.H. Protein quality evaluation in processed human foods by the digestible indispensable amino acid score methodology. In *Energy and Protein Metabolism and Nutrition*; EAAP Scientific Series: Rome, Italy, 2019; Volume 138, pp. 423–424. ISBN 978-90-8686-340-2.
84. Ahmad, S.; Anzar, A.; Srivastava, A.K.; Srivastava, P.K. Effect of curing, antioxidant treatment, and smoking of buffalo meat on ph, total plate count, sensory characteristics, and shelf life during refrigerated storage. *Int. J. Food Prop.* **2005**, *8*, 139–150. [CrossRef]

85. Janiszewski, P.; Grześkowiak, E.; Lisiak, D.; Borys, B.; Borzuta, K.; Pospiech, E.; Poławska, E. The influence of thermal processing on the fatty acid profile of pork and lamb meat fed diet with increased levels of unsaturated fatty acids. *Meat Sci.* **2016**, *111*, 161–167. [CrossRef]
86. Sindelar, J.J.; Milkowski, A.L. Human safety controversies surrounding nitrate and nitrite in the diet. *Nitric Oxide Biol. Chem.* **2012**, *26*, 259–266. [CrossRef]
87. Jakszyn, P.; Gonzalez, C.A. Nitrosamine and related food intake and gastric and oesophageal cancer risk: A systematic review of the epidemiological evidence. *World J. Gastroenterol.* **2006**, *12*, 4296–4303. [CrossRef]
88. Gassara, F.; Kouassi, A.P.; Brar, S.K.; Belkacemi, K. Green alternatives to nitrates and nitrites in meat-based products—A review. *Crit. Rev. Food Sci. Nutr.* **2016**, *56*, 2133–2148. [CrossRef]
89. Sindelar, J. Investigating uncured no nitrate or nitrite added processed meat products. AI State University: Ames, AI, USA, 2006.
90. Vega-Warner, V.; Merkel, R.A.; Smith, D.M. Composition, solubility and gel properties of salt soluble proteins from two bovine muscle types. *Meat Sci.* **1999**, *51*, 197–203. [CrossRef]
91. Gómez, M.; Lorenzo, J.M. Effect of fat level on physicochemical, volatile compounds and sensory characteristics of dry-ripened "chorizo" from Celta pig breed. *Meat Sci.* **2013**, *95*, 658–666. [CrossRef] [PubMed]
92. Pietrasik, Z.; Gaudette, N.J. The impact of salt replacers and flavor enhancer on the processing characteristics and consumer acceptance of restructured cooked hams. *Meat Sci.* **2014**, *96*, 1165–1170. [CrossRef] [PubMed]
93. Ruusunen, M.; Vainionpää, J.; Puolanne, E.; Lyly, M.; Lähteenmäki, L.; Niemistö, M.; Ahvenainen, R. Effect of sodium citrate, carboxymethyl cellulose and carrageenan levels on quality characteristics of low-salt and low-fat bologna type sausages. *Meat Sci.* **2003**, *64*, 371–381. [CrossRef]
94. Ripollés, S.; Campagnol, P.C.B.; Armenteros, M.; Aristoy, M.C.; Toldrá, F. Influence of partial replacement of NaCl with KCl, $CaCl_2$ and $MgCl_2$ on lipolysis and lipid oxidation in dry-cured ham. *Meat Sci.* **2011**, *89*, 58–64. [CrossRef]
95. Rama, R.; Chiu, N.; Silva, M.C.D.; Hewson, L.; Hort, J.; Fisk, I.D. Impact of salt crystal size on in-mouth delivery of sodium and saltiness perception from snack foods. *J. Texture Stud.* **2013**, *44*, 338–345. [CrossRef]
96. Barbut, S.; Maurer, A.J.; Lindsay, R.C. Effects of reduced sodium chloride and added phosphates on physical and sensory properties of turkey frankfurters. *J. Food Sci.* **1988**, *53*, 62–66. [CrossRef]
97. Ertbjerg, P.; Mielche, M.M.; Larsen, L.M.; Møller, A.J. Relationship between proteolytic changes and tenderness in prerigor lactic acid marinated beef. *J. Sci. Food Agric.* **1999**, *79*, 970–978. [CrossRef]
98. Dimakopoulou-Papazoglou, D.; Katsanidis, E. Osmotic processing of meat: Mathematical modeling and quality parameters. *Food Eng. Rev.* **2020**, *12*, 32–47. [CrossRef]
99. Alvarado, C.; McKee, S. Marination to improve functional properties and safety of poultry meat. *J. Appl. Poult. Res.* **2007**, *16*, 113–120. [CrossRef]
100. Griffiths, N.M.; Wilkinson, C.C.L. The effects on broiler chicken of polyphosphate injection during commercial processing. *Int. J. Food Sci. Technol.* **1978**, *13*, 541–549. [CrossRef]
101. Brewer, M.S.; Jensen, J.; Prestat, C.; Zhu, L.G.; Mckeith, F.K. Visual acceptability and consumer purchase intent of enhanced pork loin roasts. *J. Muscle Foods* **2002**, *13*, 53–68. [CrossRef]
102. Sheard, P.R.; Tali, A. Injection of salt, tripolyphosphate and bicarbonate marinade solutions to improve the yield and tenderness of cooked pork loin. *Meat Sci.* **2004**, *68*, 305–311. [CrossRef] [PubMed]
103. Hoffman, L.C.; Muller, M.; Vermaak, A. Sensory and preference testing of selected beef muscles infused with a phosphate and lactate blend. *Meat Sci.* **2008**, *80*, 1055–1060. [CrossRef] [PubMed]
104. Detienne, N.A.; Reynolds, A.E.; Wicker, L. Phosphate marination of pork loins at high and low injection pressures. *J. Food Qual.* **2003**, *26*, 1–14. [CrossRef]
105. McGee, M.R.; Henry, K.L.; Brooks, J.C.; Ray, F.K.; Morgan, J.B. Injection of sodium chloride, sodium tripolyphosphate, and sodium lactate improves Warner–Bratzler shear and sensory characteristics of pre-cooked inside round roasts. *Meat Sci.* **2003**, *64*, 273–277. [CrossRef]
106. Vote, D.J.; Platter, W.J.; Tatum, J.D.; Schmidt, G.R.; Belk, K.E.; Smith, G.C.; Speer, N.C. Injection of beef strip loins with solutions containing sodium tripolyphosphate, sodium lactate, and sodium chloride to enhance palatability. *J. Anim. Sci.* **2000**, *78*, 952–957. [CrossRef]
107. Robbins, K.; Jensen, J.; Ryan, K.J.; Homco-Ryan, C.; Mckeith, F.K.; Brewer, M.S. Enhancement effects on sensory and retail display characteristics of beef rounds. *J. Muscle Foods* **2002**, *13*, 279–288. [CrossRef]

108. Sawyer, J.T.; Apple, J.K.; Johnson, Z.B. The impact of lactic acid concentration and sodium chloride on pH, water-holding capacity, and cooked color of injection-enhanced dark-cutting beef. *Meat Sci.* **2008**, *79*, 317–325. [CrossRef]
109. Burke, R.M.; Monahan, F.J. The tenderisation of shin beef using a citrus juice marinade. *Meat Sci.* **2003**, *63*, 161–168. [CrossRef]
110. Seuss, I.; Martin, M. The influence of marinating with food acids on the composition and sensory properties of beef. *Fleischwirtschaft* **1993**, *73*, 292–295.
111. Corral, S.; Salvador, A.; Flores, M. Salt reduction in slow fermented sausages affects the generation of aroma active compounds. *Meat Sci.* **2013**, *93*, 776–785. [CrossRef] [PubMed]
112. Aaslyng, M.D.; Vestergaard, C.; Koch, A.G. The effect of salt reduction on sensory quality and microbial growth in hotdog sausages, bacon, ham and salami. *Meat Sci.* **2014**, *96*, 47–55. [CrossRef] [PubMed]
113. Jiménez-Colmenero, F.; Reig, M.; Toldrá, F. New approaches for the development of functional meat products. In *Advanced Technologies for Meat Processing*; Toldrá, F., Nollet, L.M., Eds.; CRC Press: Boca Raton, FL, USA, 2018; p. 275.
114. Jiménez-Colmenero, F.; Carballo, J.; Cofrades, S. Healthier meat and meat products: Their role as functional foods. *Meat Sci.* **2001**, *59*, 5–13. [CrossRef]
115. Olmedilla-Alonso, B.; Jiménez-Colmenero, F.; Sánchez-Muniz, F.J. Development and assessment of healthy properties of meat and meat products designed as functional foods. *Meat Sci.* **2013**, *95*, 919–930. [CrossRef]
116. Keeton, J.T. Low-fat meat products-technological problems with processing. *Meat Sci.* **1994**, *36*, 261–276. [CrossRef]
117. Paneras, E.D.; Bloukas, J.G.; Filis, D.G. Production of low-fat frankfurters with vegetable oils following the dietary guidelines for fatty acids. *J. Muscle Foods* **1998**, *9*, 111–126. [CrossRef]
118. Marquez, E.J.; Ahmed, E.M.; West, R.L.; Johnson, D.D. Emulsion stability and sensory quality of beef frankfurters produced at different fat or peanut oil levels. *J. Food Sci.* **1989**, *54*, 867–870. [CrossRef]
119. Jiménez-Colmenero, F. Healthier lipid formulation approaches in meat-based functional foods. Technological options for replacement of meat fats by non-meat fats. *Trends Food Sci. Technol.* **2007**, *18*, 567–578. [CrossRef]
120. Da Silva, S.L.; Amaral, J.T.; Ribeiro, M.; Sebastião, E.E.; Vargas, C.; de Lima Franzen, F.; Schneider, G.; Lorenzo, J.M.; Fries, L.L.M.; Cichoski, A.J.; et al. Fat replacement by oleogel rich in oleic acid and its impact on the technological, nutritional, oxidative, and sensory properties of Bologna-type sausages. *Meat Sci.* **2019**, *149*, 141–148. [CrossRef]
121. Gómez, I.; Sarriés, M.V.; Ibañez, F.C.; Beriain, M.J. Quality characteristics of a low-fat beef patty enriched by polyunsaturated fatty acids and vitamin D3. *J. Food Sci.* **2018**, *83*, 454–463. [CrossRef] [PubMed]
122. Beriain, M.J.; Gómez, I.; Sánchez, M.; Insausti, K.; Sarriés, M.V.; Ibañez, F.C. The reformulation of a beef patty enriched with n-3 fatty acids and vitamin D3 influences consumers' response under different information scenarios. *Foods* **2020**, *9*, 506. [CrossRef] [PubMed]
123. Jiménez-Colmenero, F.; Delgado-Pando, G. Fibre-enriched meat products. In *Fibre-Rich and WholegrAIn Foods*; Delcour, J.A., Poutanen, K., Delcour, J.A., Poutanen, K., Eds.; Woodhead Publishing Series in Food Science, Technology and Nutrition; Woodhead Publishing Limited: Cambridge UK, 2013; pp. 329–347. ISBN 978-0-85709-038-6.
124. Kim, J.S.; Godber, J.S.; Prinaywiwatkul, W. Restructured beef roasts containing rice bran oil and fiber influences cholesterol oxidation and nutritional profile. *J. Muscle Foods* **2000**, *11*, 111–127. [CrossRef]
125. Fernández-Ginés, J.M.; Fernández-López, J.; Sayas-Barberá, E.; Sendra, E.; Pérez-Álvarez, J.A. Lemon albedo as a new source of dietary fiber: Application to bologna sausages. *Meat Sci.* **2004**, *67*, 7–13. [CrossRef]
126. Tobin, B.D.; O'Sullivan, M.G.; Hamill, R.M.; Kerry, J.P. Effect of varying salt and fat levels on the sensory and physiochemical quality of frankfurters. *Meat Sci.* **2012**, *92*, 659–666. [CrossRef]
127. Ortega-Heras, M.; Villarroel, E.; Mateos, S.; García-Lomillo, J.; Rovira, J.; González-Sanjosé, M.L. Application of a seasoning obtained from red grape pomace as a salt replacer for the elaboration of marinated chicken breasts: Study of their physical-chemical and sensory properties and microbiological stability. *CyTA J. Food* **2020**, *18*, 122–131. [CrossRef]
128. Guo, X.; Tao, S.; Pan, J.; Lin, X.; Ji, C.; Liang, H.; Dong, X.; Li, S. Effects of l-Lysine on the physiochemical properties and sensory characteristics of salt-reduced reconstructed ham. *Meat Sci.* **2020**, *166*, 108133. [CrossRef]

129. Carvalho, C.B.; Madrona, G.S.; da Silva Corradine, S.; Reche, P.M.; dos Santos Pozza, M.S.; de Prado, I.N. Evaluation of quality factors of bovine and chicken meat marinated with reduced sodium content. *Food Sci. Technol.* **2013**, *33*, 776–783. [CrossRef]
130. Campagnol, P.C.B.; dos Santos, B.A.; Terra, N.N.; Pollonio, M.A.R. Lysine, disodium guanylate and disodium inosinate as flavor enhancers in low-sodium fermented sausages. *Meat Sci.* **2012**, *91*, 334–338. [CrossRef]
131. McGough, M.M.; Sato, T.; Rankin, S.A.; Sindelar, J.J. Reducing sodium levels in frankfurters using naturally brewed soy sauce. *Meat Sci.* **2012**, *91*, 69–78. [CrossRef]
132. Tobin, B.D.; O'Sullivan, M.G.; Hamill, R.M.; Kerry, J.P. The impact of salt and fat level variation on the physiochemical properties and sensory quality of pork breakfast sausages. *Meat Sci.* **2013**, *93*, 145–152. [CrossRef] [PubMed]
133. Park, J.; Rhee, K.S.; Keeton, J.T.; Rhee, K.C. Properties of low-fat frankfurters containing monounsaturated and omega-3 polyunsaturated oils. *J. Food Sci.* **1989**, *54*, 500–504. [CrossRef]
134. Troutt, E.S.; Hunt, M.C.; Johnson, D.E.; Claus, J.R.; Kastner, C.L.; Kropf, D.H. Characteristics of low-fat ground beef containing texture-modifying ingredients. *J. Food Sci.* **1992**, *57*, 19–24. [CrossRef]
135. Bis-Souza, C.V.; Pateiro, M.; Domínguez, R.; Penna, A.L.B.; Lorenzo, J.M.; Silva Barretto, A.C. Impact of fructooligosaccharides and probiotic strains on the quality parameters of low-fat Spanish Salchichón. *Meat Sci.* **2020**, *159*, 107936. [CrossRef]
136. Rubio, B.; Martínez, B.; García-Cachán, M.D.; Rovira, J.; Jaime, I. Effect of the packaging method and the storage time on lipid oxidation and colour stability on dry fermented sausage Salchichón manufactured with raw material with a high level of mono and polyunsaturated fatty acids. *Meat Sci.* **2008**, *80*, 1182–1187. [CrossRef]
137. Descalzo, A.M.; Sancho, A.M. A review of natural antioxidants and their effects on oxidative status, odor and quality of fresh beef produced in Argentina. *Meat Sci.* **2008**, *79*, 423–436. [CrossRef]
138. Scollan, N.; Hocquette, J.F.; Nuernberg, K.; Dannenberger, D.; Richardson, I.; Moloney, A. Innovations in beef production systems that enhance the nutritional and health value of beef lipids and their relationship with meat quality. *Meat Sci.* **2006**, *74*, 17–33. [CrossRef]
139. Gómez, I.; Beriain, M.J.; Sarriés, M.V.; Insausti, K.; Mendizabal, J.A. Low-fat beef patties with augmented omega-3 fatty acid and CLA levels and influence of grape seed extract. *J. Food Sci.* **2014**, *79*, S2368–S2376. [CrossRef]
140. Cofrades, S.; Guerra, M.A.; Carballo, J.; Fernández-Martín, F.; Colmenero, F.J. Plasma protein and soy fiber content effect on bologna sausage properties as influenced by fat level. *J. Food Sci.* **2000**, *65*, 281–287. [CrossRef]
141. Arshad, M.S.; Kwon, J.H.; Imran, M.; Sohaib, M.; Aslam, A.; Nawaz, I.; Amjad, Z.; Khan, U.; Javed, M. Plant and bacterial proteases: A key towards improving meat tenderization, a mini review. *Cogent Food Agric.* **2016**, *2*, 1261780. [CrossRef]
142. Schenková, N.; Šikulová, M.; Jeleníková, J.; Pipek, P.; Houška, M.; Marek, M. Influence of high isostatic pressure and papain treatment on the quality of beef meat. *High Press. Res.* **2007**, *27*, 163–168. [CrossRef]
143. Kolle, B.K.; McKenna, D.R.; Savell, J.W. Methods to increase tenderness of individual muscles from beef rounds when cooked with dry or moist heat. *Meat Sci.* **2004**, *68*, 145–154. [CrossRef]
144. Ramezani, R.; Aminlari, M.; Fallahi, H. Effect of chemically modified soy proteins and ficin-tenderized meat on the quality attributes of sausage. *J. Food Sci.* **2003**, *68*, 85–88. [CrossRef]
145. Muguruma, M.; Tsuruoka, K.; Katayama, K.; Erwanto, Y.; Kawahara, S.; Yamauchi, K.; Sathe, S.K.; Soeda, T. Soybean and milk proteins modified by transglutaminase improves chicken sausage texture even at reduced levels of phosphate. *Meat Sci.* **2003**, *63*, 191–197. [CrossRef]
146. Kuraishi, C.; Yamazaki, K.; Susa, Y. Transglutaminase: Its utilization in the food industry. *Food Rev. Int.* **2001**, *17*, 221–246. [CrossRef]
147. Kuraishi, C.; Sakamoto, J.; Yamazaki, K.; Susa, Y.; Kuhara, C.; Soeda, T. Production of restructured meat using microbial transglutaminase without salt or cooking. *J. Food Sci.* **1997**, *62*, 488–490. [CrossRef]
148. Tseng, T.F.; Liu, D.C.; Chen, M.T. Evaluation of transglutaminase on the quality of low-salt chicken meat-balls. *Meat Sci.* **2000**, *55*, 427–431. [CrossRef]
149. Kilic, B. Effect of microbial transglutaminase and sodium caseinate on quality of chicken döner kebab. *Meat Sci.* **2003**, *63*, 417–421. [CrossRef]

150. Yang, X.; Zhang, Y. Expression of recombinant transglutaminase gene in *Pichia pastoris* and its uses in restructured meat products. *Food Chem.* **2019**, *291*, 245–252. [CrossRef]
151. Cofrades, S.; López-López, I.; Ruiz-Capillas, C.; Triki, M.; Jiménez-Colmenero, F. Quality characteristics of low-salt restructured poultry with microbial transglutaminase and seaweed. *Meat Sci.* **2011**, *87*, 373–380. [CrossRef]
152. Tsao, C.Y.; Kao, Y.C.; Hsieh, J.F.; Jiang, S.T. Use of soy protein and microbial transglutaminase as a binder in low-sodium restructured meats. *J. Food Sci.* **2002**, *67*, 3502–3506. [CrossRef]
153. Raveendran, S.; Parameswaran, B.; Ummalyma, S.B.; Abraham, A.; Mathew, A.K.; Madhavan, A.; Rebello, S.; Pandey, A. Applications of microbial enzymes in food industry. *Food Technol. Biotechnol.* **2018**, *56*, 16–30. [CrossRef] [PubMed]
154. Singh, P.K.; Shrivastava, N.; Ojha, B.K. Enzymes in the meat industry. In *Enzymes in Food Biotechnology*; Kuddus, M., Ed.; Academic Press: London, UK, 2019; pp. 111–128. ISBN 978-0-12-813280-7.
155. Ansorena, D.; Zapelena, M.J.; Astiasarán, I.; Bello, J. Simultaneous addition of palatase M and protease P to a dry fermented sausage (*chorizo de Pamplona*) elaboration: Effect over peptidic and lipid fractions. *Meat Sci.* **1998**, *50*, 37–44. [CrossRef]
156. Herranz, B.; Fernández, M.; Hierro, E.; Bruna, J.M.; Ordóñez, J.A.; de la Hoz, L. Use of *Lactococcus lactis* subsp. *cremoris* NCDO 763 and α-ketoglutarate to improve the sensory quality of dry fermented sausages. *Meat Sci.* **2004**, *66*, 151–163. [CrossRef]
157. Cunningham, F.E.; Tiede, L.M. Properties of selected poultry products treated with a tenderizing marinade. *Poult. Sci.* **1981**, *60*, 2475–2479. [CrossRef]
158. Quaglia, G.B.; Lombardi, M.; Sinesio, F.; Bertone, A.; Menesatti, P. Effect of enzymatic treatment on tenderness characteristics of freeze-dried meat. *Food Sci. Technol. Lebensm. Wiss. Technol.* **1992**, *25*, 143–145.
159. Pietrasik, Z.; Li-Chan, E.C.Y. Response surface methodology study on the effects of salt, microbial transglutaminase and heating temperature on pork batter gel properties. *Food Res. Int.* **2002**, *35*, 387–396. [CrossRef]
160. Ahmad, M.; John, S.; Bosco, D.; Ahmad, S. Evaluation of shelf life of retort pouch packaged Rogan josh, a traditional meat curry of Kashmir, India. *Food Packag. Shelf Life* **2017**, *12*, 76–82. [CrossRef]
161. Zhu, M.; Du, M.; Cordray, J.; Ahn, D.U. Control of *Listeria monocytogenes* contamination in ready-to-eat meat products. *Compr. Rev. Food Sci. Food Saf.* **2005**, *4*, 34–42. [CrossRef]
162. Sun, X.D.; Holley, R.A. Factors influencing gel formation by myofibrillar proteins in muscle foods. *Compr. Rev. Food Sci. Food Saf.* **2011**, *10*, 33–51. [CrossRef]
163. Boles, J.A. Thermal processing. In *Handbook of Meat Processing*; Toldrá, F., Ed.; John Wiley & Sons, Ltd.: Ames, AI, USA, 2010; pp. 169–183. ISBN 978-0-8138-2089-7.
164. Falowo, A.B.; Fayemi, P.O.; Muchenje, V. Natural antioxidants against lipid–protein oxidative deterioration in meat and meat products: A review. *Food Res. Int.* **2014**, *64*, 171–181. [CrossRef] [PubMed]
165. Vargas-Sánchez, R.D.; Ibarra-Arias, F.J.; del Mar Torres-Martínez, B.; Sánchez-Escalante, A.; Torrescano-Urrutia, G.R. Use of natural ingredients in Japanese quail diet and their effect on carcass and meat quality—A review. *Asian Australas. J. Anim. Sci.* **2019**, *32*, 1641–1656. [CrossRef] [PubMed]
166. Czerwonka, M.; Szterk, A. The effect of meat cuts and thermal processing on selected mineral concentration in beef from Holstein-Friesian bulls. *Meat Sci.* **2015**, *105*, 75–80. [CrossRef] [PubMed]
167. McNeill, S.; Van Elswyk, M.E. Red meat in global nutrition. *Meat Sci.* **2012**, *92*, 166–173. [CrossRef] [PubMed]
168. Wood, J.D.; Enser, M.; Fisher, A.V.; Nute, G.R.; Sheard, P.R.; Richardson, R.I.; Hughes, S.I.; Whittington, F.M. Fat deposition, fatty acid composition and meat quality: A review. *Meat Sci.* **2008**, *78*, 343–358. [CrossRef] [PubMed]
169. Zhang, W.; Xiao, S.; Samaraweera, H.; Lee, E.J.; Ahn, D.U. Improving functional value of meat products. *Meat Sci.* **2010**, *86*, 15–31. [CrossRef]
170. Rajan, S.; Kulkarni, V.V.; Chandirasekaran, V. Preparation and storage stability of retort processed Chettinad chicken. *J. Food Sci. Technol.* **2014**, *51*, 173–177. [CrossRef]
171. Fang, Z.; Zhao, Y.; Warner, R.D.; Johnson, S.K. Active and intelligent packaging in meat industry. *Trends Food Sci. Technol.* **2017**, *61*, 60–71. [CrossRef]
172. Rousset, S.; Renerre, M. Effect of CO2 or vacuum packaging on normal and high pH meat shelf-life. *Int. J. Food Sci. Technol.* **1991**, *26*, 641–652. [CrossRef]

173. Bellés, M.; Alonso, V.; Roncalés, P.; Beltrán, J.A. The combined effects of superchilling and packaging on the shelf life of lamb. *Meat Sci.* **2017**, *133*, 126–132. [CrossRef]
174. Łopacka, J.; Półtorak, A.; Wierzbicka, A. Effect of MAP, vacuum skin-pack and combined packaging methods on physicochemical properties of beef steaks stored up to 12days. *Meat Sci.* **2016**, *119*, 147–153. [CrossRef] [PubMed]
175. Rajaei, A.; Hadian, M.; Mohsenifar, A.; Rahmani-Cherati, T.; Tabatabaei, M. A coating based on clove essential oils encapsulated by chitosan-myristic acid nanogel efficiently enhanced the shelf-life of beef cutlets. *Food Packag. Shelf Life* **2017**, *14*, 137–145. [CrossRef]
176. Duran, A.; Kahve, H.I. The effect of chitosan coating and vacuum packaging on the microbiological and chemical properties of beef. *Meat Sci.* **2020**, *162*, 107961. [CrossRef] [PubMed]
177. Nowak, A.; Danuta, K.; Krala, L.; Piotrowska, M.; Czyzowska, A. The effects of thyme (*Thymus vulgaris*) and rosemary (*Rosmarinus officinalis*) essential oils on *Brochothrix thermosphacta* and on the shelf life of beef packaged in high-oxygen modified atmosphere. *Food Microbiol.* **2012**, *32*, 212–216. [CrossRef]
178. Quesada, J.; Sendra, E.; Navarro, C.; Sayas-Barberá, E. Antimicrobial active packaging including chitosan films with *Thymus vulgaris* L. essential oil for ready-to-eat meat. *Foods* **2016**, *5*, 57. [CrossRef] [PubMed]
179. Kanatt, S.R.; Rao, M.S.; Chawla, S.P.; Sharma, A. Effects of chitosan coating on shelf-life of ready-to-cook meat products during chilled storage. *LWT Food Sci. Technol.* **2013**, *53*, 321–326. [CrossRef]
180. Soultos, N.; Tzikas, Z.; Abrahim, A.; Georgantelis, D.; Ambrosiadis, I. Chitosan effects on quality properties of Greek style fresh pork sausages. *Meat Sci.* **2008**, *80*, 1150–1156. [CrossRef]
181. Kuswandi, B.; Nurfawaidi, A. On-package dual sensors label based on pH indicators for real-time monitoring of beef freshness. *Food Control* **2017**, *82*. [CrossRef]
182. Biji, K.B.; Ravishankar, C.N.; Mohan, C.O.; Srinivasa Gopal, T.K. Smart packaging systems for food applications: A review. *J. Food Sci. Technol.* **2015**, *52*, 6125–6135. [CrossRef]
183. McMillin, K.W. Advancements in meat packaging. *Meat Sci.* **2017**, *132*, 153–162. [CrossRef]
184. Vargas, M.; Albors, A.; Chiralt, A. Application of chitosan-sunflower oil edible films to pork meat hamburgers. *Procedia Food Sci.* **2011**, *1*, 39–43. [CrossRef]
185. Umaraw, P.; Munekata, P.E.S.; Verma, A.K.; Barba, F.J.; Singh, V.P.; Kumar, P.; Lorenzo, J.M. Edible films/coating with tailored properties for active packaging of meat, fish and derived products. *Trends Food Sci. Technol.* **2020**, *98*, 10–24. [CrossRef]
186. Fu, Q.Q.; Liu, R.; Zhou, G.H.; Zhang, W.G. Effects of packaging methods on the color of beef muscles through influencing myoglobin status, metmyoglobin reductase activity and lipid oxidation. *J. Food Process. Preserv.* **2017**, *41*, e12740. [CrossRef]
187. Frank, D.C.; Geesink, G.; Alvarenga, T.I.R.C.; Polkinghorne, R.; Stark, J.; Lee, M.; Warner, R. Impact of high oxygen and vacuum retail ready packaging formats on lamb loin and topside eating quality. *Meat Sci.* **2017**, *123*, 126–133. [CrossRef]
188. Kameník, J.; Saláková, A.; Pavlík, Z.; Bořilová, G.; Hulanková, R.; Steinhauserová, I. Vacuum skin packaging and its effect on selected properties of beef and pork meat. *Eur. Food Res. Technol.* **2014**, *239*, 395–402. [CrossRef]
189. Narváez-Bravo, C.; Rodas-González, A.; Ding, C.; López-Campos, O.; Galbraith, J.; Larsen, I.L.; Ye, J.; Siegel, D.; Aalhus, J.L. Effects of novel nitrite packaging film on the bacterial growth of bison strip-loin steaks. *J. Food Process. Preserv.* **2017**, *41*, e13311. [CrossRef]
190. 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]
191. Djenane, D.; Beltrán, J.A.; Camo, J.; Roncalés, P. Influence of vacuum-ageing duration of whole beef on retail shelf life of steaks packaged with oregano (*Origanum vulgare* L.) active film under high O_2. *J. Food Sci. Technol.* **2016**, *53*, 4244–4257. [CrossRef]
192. Battisti, R.; Fronza, N.; Vargas Június, Á.; da Silveira, S.M.; Damas, M.S.P.; Quadri, M.G.N. Gelatin-coated paper with antimicrobial and antioxidant effect for beef packaging. *Food Packag. Shelf Life* **2017**, *11*, 115–124. [CrossRef]
193. Zimoch-Korzycka, A.; Jarmoluk, A. Polysaccharide-based edible coatings containing cellulase for improved preservation of meat quality during storage. *Molecules* **2017**, *22*, 390. [CrossRef]

194. Park, H.Y.; Kim, S.J.; Kim, K.M.; You, Y.S.; Kim, S.Y.; Han, J. Development of antioxidant packaging material by applying corn-zein to LLDPE film in combination with phenolic compounds. *J. Food Sci.* **2012**, *77*, E273–E279. [CrossRef] [PubMed]
195. Wu, Y.; Weller, C.L.; Hamouz, F.; Cuppett, S.; Schnepf, M. Moisture loss and lipid oxidation for precooked ground-beef patties packaged in edible starch-alginate-based composite films. *J. Food Sci.* **2001**, *66*, 486–493. [CrossRef]
196. Hempel, A.W.; Papkovsky, D.B.; Kerry, J.P. Use of optical oxygen sensors in non-destructively determining the levels of oxygen present in combined vacuum and modified atmosphere packaged pre-cooked convenience-style foods and the use of ethanol emitters to extend product shelf-life. *Foods* **2013**, *2*, 507–520. [CrossRef] [PubMed]
197. Thangavelu, K.P.; Kerry, J.P.; Tiwari, B.K.; McDonnell, C.K. Novel processing technologies and ingredient strategies for the reduction of phosphate additives in processed meat. *Trends Food Sci. Technol.* **2019**, *94*, 43–53. [CrossRef]
198. Scotter, M.J.; Castle, L. Chemical interactions between additives in foodstuffs: A review. *Food Addit. Contam.* **2004**, *21*, 93–124. [CrossRef]
199. Nair, M.S.; Nair, D.V.T.; Johny, A.K.; Venkitanarayanan, K. Use of food preservatives and additives in meat and their detection techniques. In *Meat Quality Analysis*; Biswas, A.K., Mandal, P.K., Eds.; Academic Press: London, UK, 2020; pp. 187–213. ISBN 978-0-12-819233-7.
200. Honikel, K.O. The use and control of nitrate and nitrite for the processing of meat products. *Meat Sci.* **2008**, *78*, 68–76. [CrossRef]
201. Karwowska, M.; Kononiuk, A. Nitrates/nitrites in food—Risk for nitrosative stress and benefits. *Antioxidants* **2020**, *9*, 241. [CrossRef]
202. Aziz, M.; Karboune, S. Natural antimicrobial/antioxidant agents in meat and poultry products as well as fruits and vegetables: A review. *Crit. Rev. Food Sci. Nutr.* **2018**, *58*, 486–511. [CrossRef]
203. Karabagias, I.; Badeka, A.; Kontominas, M.G. Shelf life extension of lamb meat using thyme or oregano essential oils and modified atmosphere packaging. *Meat Sci.* **2011**, *88*, 109–116. [CrossRef]
204. Radha krishnan, K.; Babuskin, S.; Azhagu Saravana Babu, P.; Sasikala, M.; Sabina, K.; Archana, G.; Sivarajan, M.; Sukumar, M. Antimicrobial and antioxidant effects of spice extracts on the shelf life extension of raw chicken meat. *Int. J. Food Microbiol.* **2014**, *171*, 32–40. [CrossRef]
205. Chan, K.W.; Khong, N.M.H.; Iqbal, S.; Ch'ng, S.E.; Younas, U.; Babji, A.S. Cinnamon bark deodorised aqueous extract as potential natural antioxidant in meat emulsion system: A comparative study with synthetic and natural food antioxidants. *J. Food Sci. Technol.* **2014**, *51*, 3269–3276. [CrossRef] [PubMed]
206. Mancini, S.; Preziuso, G.; Dal Bosco, A.; Roscini, V.; Szendrő, Z.; Fratini, F.; Paci, G. Effect of turmeric powder (*Curcuma longa* L.) and ascorbic acid on physical characteristics and oxidative status of fresh and stored rabbit burgers. *Meat Sci.* **2015**, *110*, 93–100. [CrossRef] [PubMed]
207. Zahid, M.A.; Choi, J.Y.; Seo, J.K.; Parvin, R.; Ko, J.; Yang, H.S. Effects of clove extract on oxidative stability and sensory attributes in cooked beef patties at refrigerated storage. *Meat Sci.* **2020**, *161*, 107972. [CrossRef] [PubMed]
208. Ahmad Mir, S.; Ahmad Masoodi, F.; Raja, J. Influence of natural antioxidants on microbial load, lipid oxidation and sensorial quality of rista—A traditional meat product of India. *Food Biosci.* **2017**, *20*, 79–87. [CrossRef]
209. Lara, M.S.; Gutierrez, J.I.; Timón, M.; Andrés, A.I. Evaluation of two natural extracts (*Rosmarinus officinalis* L. and *Melissa officinalis* L.) as antioxidants in cooked pork patties packed in MAP. *Meat Sci.* **2011**, *88*, 481–488. [CrossRef]
210. Vasilatos, G.C.; Savvaidis, I.N. Chitosan or rosemary oil treatments, singly or combined to increase turkey meat shelf-life. *Int. J. Food Microbiol.* **2013**, *166*, 54–58. [CrossRef]
211. Fernandes, R.P.P.; Trindade, M.A.; Lorenzo, J.M.; Munekata, P.E.S.; de Melo, M.P. Effects of oregano extract on oxidative, microbiological and sensory stability of sheep burgers packed in modified atmosphere. *Food Control.* **2016**, *63*, 65–75. [CrossRef]
212. Horita, C.N.; Farías-Campomanes, A.M.; Barbosa, T.S.; Esmerino, E.A.; da Cruz, A.G.; Bolini, H.M.A.; Meireles, M.A.A.; Pollonio, M.A.R. The antimicrobial, antioxidant and sensory properties of garlic and its derivatives in Brazilian low-sodium frankfurters along shelf-life. *Food Res. Int.* **2016**, *84*, 1–8. [CrossRef]

213. Bañón, S.; Díaz, P.; Rodríguez, M.; Garrido, M.D.; Price, A. Ascorbate, green tea and grape seed extracts increase the shelf life of low sulphite beef patties. *Meat Sci.* **2007**, *77*, 626–633. [CrossRef]
214. Gómez, I.; Beriain, M.J.; Mendizabal, J.A.; Realini, C.; Purroy, A. Shelf life of ground beef enriched with omega-3 and/or conjugated linoleic acid and use of grape seed extract to inhibit lipid oxidation. *Food Sci. Nutr.* **2016**, *4*, 67–79. [CrossRef]
215. Price, A.; Díaz, P.; Bañón, S.; Garrido, M.D. Natural extracts versus sodium ascorbate to extend the shelf life of meat-based ready-to-eat meals. *Food Sci. Technol. Int.* **2013**. [CrossRef] [PubMed]
216. Tamkutė, L.; Gil, B.M.; Carballido, J.R.; Pukalskienė, M.; Venskutonis, P.R. Effect of cranberry pomace extracts isolated by pressurized ethanol and water on the inhibition of food pathogenic/spoilage bacteria and the quality of pork products. *Food Res. Int.* **2019**, *120*, 38–51. [CrossRef] [PubMed]
217. Kryževičūtė, N.; Jaime, I.; Diez, A.M.; Rovira, J.; Venskutonis, P.R. Effect of raspberry pomace extracts isolated by high pressure extraction on the quality and shelf-life of beef burgers. *Int. J. Food Sci. Technol.* **2017**, *52*, 1852–1861. [CrossRef]
218. García-Lomillo, J.; González-SanJosé, M.L.; Del Pino-García, R.; Rivero-Pérez, M.D.; Muñiz-Rodríguez, P. Antioxidant and antimicrobial properties of wine byproducts and their potential uses in the food industry. *J. Agric. Food Chem.* **2014**, *62*, 12595–12602. [CrossRef] [PubMed]
219. García-Lomillo, J.; González-SanJosé, M.L. Applications of wine pomace in the food industry: Approaches and functions. *Compr. Rev. Food Sci. Food Saf.* **2017**, *16*, 3–22. [CrossRef]
220. Garcia-Lomillo, J.; González-SanJosé, M.L.; Skibsted, L.H.; Jongberg, S. Effect of skin wine pomace and sulfite on protein oxidation in beef patties during high oxygen atmosphere storage. *Food Bioprocess. Technol.* **2016**, *9*, 532–542. [CrossRef]
221. Yogesh, K.; Ahmad, T.; Manpreet, G.; Mangesh, K.; Das, P. Characteristics of chicken nuggets as affected by added fat and variable salt contents. *J. Food Sci. Technol.* **2013**, *50*, 191–196. [CrossRef]
222. Viuda-Martos, M.; Fernández-López, J.; Sayas-Barbera, E.; Sendra, E.; Navarro, C.; Pérez-Alvarez, J.A. Citrus co-products as technological strategy to reduce residual nitrite content in meat products. *J. Food Sci.* **2009**, *74*, R93–R100. [CrossRef]