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Review

New Trends in Meat Packaging

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Abstract: The term 'packaging' refers to the technological intervention aimed at the protection of food from a variety of factors, which provokes the product detriment. Packaging is considered as one of the most interesting technological aspects and a constantly evolving issue in food production. This paper aims at the evaluation of the properties of packaging currently used in the meat industry and analyses the advantages, the disadvantages and the microbiota involved. Packaging is a coordinated system, which prepares the products for transportation, distribution, storage, marketing and consumption. Even if several packaging alternatives are proposed, the common purpose is to guarantee high standards, yet maintaining the required characteristics as long as possible. Meat is a dynamic system with a limited shelf-life and the nutritional and sensory properties may change during storage due to microbial activity and physical or chemical changes. Microbial spoilage, for instance, determines an impact in meat, producing unattractive odours, flavours, discolouration, gas and slime.

Keywords: packaging; vacuum; MAP; meat spoilage; smart packaging; intelligent packaging

1. Introduction

Food security and food safety are two sides of the same coin. From one side, we have to answer to the pressing query: "How we will feed an extra two billion people by the middle of this century?" [1,2], on the other side, foodborne illness is still a current, costly threat for human health and each year, more than 9 million foodborne illnesses are caused by a major pathogen in the United States [3]. In order to face these challenges, one of the several approaches carried out is the constant improvement and updating of food packaging. Packaging is defined as the container which preserves, maintains and protects products from the environment, advertises, makes them user-friendly and easy sealable [4]. An effective food packaging technology should maintain product characteristics at the point of sale, producing less food waste and environmental impact [5].

Since ancient times, man has endeavoured to preserve the procured food, trying to avoid alterations and contaminations which could make it uneatable [6]. From 6000 BC, an empirical "primitive vacuum" was introduced, eliminating the air from holes and subsequently from containers, according to the possibility of the period. Dated back to the early 90s, other studies revealed how an increase in CO_2 concentration could extend the shelf-life of food. From those findings, the method of modifying the percentages of air constituents modernised the food preservation [6].

These considerations introduce the fundamental concept in the context of food production: shelf-life. The shelf-life of a product is, under certain conditions of storage, the time limit within the progress of individual reactive events that determine imperceptible changes in the sensory plan, still acceptable in terms of safety [7]. Nowadays, this aspect is closely related to packaging and technological intervention aimed at food preservation from multiple alteration processes [8].

Among the commercial foods, meat is one of the most perishable, and many factors can influence the shelf-life: briefly, bacterial growth, enzymatic activity and oxidation processes. Some factors are affected by package type and environment, in particular at the point of sale [9]. The meat industry is firmly interested in processing methods that provide a long shelf-life and protective packaging methods.

This review article aims at illustrating meat packaging technology and provides an insight of the characteristics of new materials.

2. Meat Packaging Overview

2.1. Function of Packaging

Packaging fulfils several functions: the first is containment at any stage of the production cycle, storage and transport [4,10]. Another fundamental purpose of packaging is to protect meat and meat products, preserving the characteristics during storage and maintaining the quality standards required for selling. Packaging protects meat and meat products during processing, storage and distribution from mechanical, chemical and biological hazards (i.e., contamination by microorganisms and parasites, contamination by dirt and toxic substances) [11]. Packaging represents a barrier against secondary contamination of meat, although the inhibition of the initial contaminant flora cannot rely only on packaging. To reduce meat spoilage, in fact, packaging has to be associated with other treatments, which limit the growth of microorganisms, according to the so-called "hurdles technology" strategy [2]. The third remarkable function is promotion; in fact, packaging is also defined as a silent seller [11]. According to the main functions, there are three levels of packaging. The primary (or sales units) is at the inner level where the packaging material is in direct contact with the product to prevent chemical and physical contamination from the environment. It is aimed at the preservation of chemical and sensory characteristics (e.g., moisture and flavour). Secondary packaging (or pre-packaging) is a sales unit completion and provides protection from mechanical stresses during storage and transport. Tertiary packaging (outer packaging) are units that facilitate the shipment, transport and palletising. The secondary and tertiary packaging are functional for food transportation [4].

2.2. Meat Packaging Materials

2.2.1. Properties of Materials Used in Meat Packaging

For meat packaging, synthetic materials used are in the form of plastic films or foil, often combined with outer packages (i.e., cardboard boxes or other materials). Materials used for inner packaging are selected according to specific requirements: flexibility, mechanical strength, lightness, odourless, hygiene, easy recycling, resistance to hot and cold temperatures, resistance to oil and fats, good barrier properties against gases, sealing capability and price of production. The properties of a material are determined by its molecular structure, molecular weight and its chemical composition. The gas permeability allows the exchange of oxygen, carbon dioxide and water vapour between the inside and the outside of the packaging, and this is a feature of the polymer materials, either synthetic (plastics) or natural (cellulosic materials).

Barrier against gases: A film has to prevent the evaporation of product moisture and the entrance of oxygen. Oxygen negatively affects unpackaged meat during prolonged storage periods, causing colour alteration due to oxidation of the myoglobin, turning the red meat colour to dark red, grey and green, and determining the formation of volatile compounds for fats oxidation and rancidity [12–14]. Beyond oxygen-proof films, oxygen-permeable foils are desirable, in case of fresh ready-to-sell meat portions, for the bright red meat colour conservation. In case of fresh meat or fresh sausages, or cooked ham, the relative moisture content is high, and the packaging material should be sufficiently water-vapour-proof, to prevent weight and quality losses by evaporation and drying during storage. For prolonged storage, such as in vacuum-packaged meat, the more permeable to oxygen the film is, the less durability the product will have [15].

Barrier against light: The exposure of meat and meat products to daylight or artificial light accelerates unattractive oxidation, rancidity and colour changes. Transparent packaging films allow attractive presentation without providing sufficient light protections; for light-sensitive products or products exposed to strong light, opaque or coloured film, such as aluminium foils, are used. It is pointed out that an efficient way to improve the light-barrier property of packaging materials is to add UV stabilisers or UV absorbers into the packaging materials [16], even including transparent packaging films. Using some metallised packaging film is also affective to slow down fat photo-oxidation [17].

2.2.2. Materials for Packaging Films

Most films used for meat packaging originate from synthetic plastic materials. The most common synthetic materials used for meat packaging are: Polyethylene (PE), Polypropylene (PP), Polyvinylchloride (PVC), Polyester (PET), Polyamide (PA), Polyvinylidenchloride (PVDC) and Ethylenvinyl alcohol (EVOH) (Tables 1 and 2) [18].

Table 1. Single-layer film application adapted from FAO [19].

Single Layer Films	Meat	Advantages	Disadvantages	Materials
Wrapping	Meat pieces, processed meat products, bone-in or boneless meat cuts or entire carcasses.	Protection from external contamination, self-adhesive "cling film"	No protection from oxygen, low water vapour permeability	PE, PA, PVC, PP
	Chilled meat portions for self-service outlets, placed in hygienic cellulose or plastic tray and tightly wrapped with single-layer plastic film.	High oxygen permeability favouring oxymyoglobin formation	Low water vapour permeability	PE or soft PVC Cellulose films less self-adhesive
Freezer storage	Meat blocks, meat cuts or smaller portions of meat or meat products.	Prevent evaporation losses, avoid freezer burn and ice formation		PA, PE

Table 2. Multi-layer film application adapted from FAO [19].

Multi-Layer Films	Oxygen Barrier	Water-Vapour Barrier	Sealant Layer	Outside Layer
PA	++	-		++
PE	-	++	++	
Combination PA/PE	++	++		
Ionomer	I		++	
PET				++
PVDC	++			
PP				++

++: highly effective, +: efective, -: non effective.

2.3. *Edible, Bio-Based and Biodegradable Materials*

More attention is given to sustainability and renewable sources, in particular plant-derived products and by-products from fermentation [20]. Robertson [21] defines bio-based packaging material as derived from primarily annually renewable sources, and thus excludes paper-based materials because the renewal time is ranging from 25 to 65 years, according to the species and country. Research is conducted to achieve a more sustainable packaging industry and improve renewal sources-based material, but the commercialisation is not still widely diffused. The main problems to solve are the solid waste problem, litter problem and pollution of marine environment [22]. Edible films (thickness < 254 μm) or sheets (thickness > 254 μm) are preformed separately from food, while edible coatings are formed directly onto the surface of the food [23]. The function of protection, from loss of moisture, gases, oil and fat migration solute transport, volatile compounds migration, is maintained, as well as the favoured handling properties [14]. The aim of this type of packaging is to extend shelf-life and improve the efficiency of the material: they can not only reduce pollution, but also contribute to the nutritional value, they can be used for heterogeneous foods and in combination with inedible materials and they can be carriers of antimicrobials and antioxidant agents. Polymers generally form coherent, stand-alone films. Edible films based on polar biopolymers (polysaccharides and proteins) are generally efficient gas barriers and have moderately good mechanical properties at low relative humidity, but both properties markedly degrade at high relative humidity. In addition, proteins and polysaccharides give water-sensitive films with poor moisture barrier performance. In contrast, hydrophobic lipids are effective against moisture migration, but their mechanical properties are much inferior to those of hydrocolloid films because of their non-polymeric nature. Most of the composite films studied to date consist of a lipid layer supported by a polysaccharide or protein layer, or lipid material dispersed in a polysaccharide or protein matrix.

Biopolymers, bio-based materials, are organic material in which carbon come exclusively from biological sources. It is a polymeric material directly extracted from or indirectly produced by biomass. It does not mean that they are edible or biodegradable, but they are easily compostable, with low environmental impact, avoiding the use of energetic sources, and are now renewable. Cellulose is among biopolymers directly extracted from natural sources. Starch could be of different origin but is always made of amylose (linear polymer of glucose) and amylopectin (ramiphied polymer of glucose). Pectines are polymers of galatturonic acid, which could be partially esterified by methyl alcohol, and they can be used to produce edible coating [24]. Future bio-based materials are likely to be blends of polymers and nanoclays (so-called bionanocomposites) in order to achieve the desired barrier and mechanical properties demanded by the food industry.

3. Packaging Classification

There are three main packaging typologies for meat products: aerobically, under vacuum and in modified atmosphere. From these, more innovative ones took place, such as the functional packaging, active or intelligent and packaging in controlled atmosphere.

3.1. Aerobic Packaging

Aerobic packaging is not considered as a technological system and is used for raw meat which is usually wrapped in stretch film on polystyrene (PS) trays (300 mm of thickness) [25]. The film materials are cellophane, constituted by cellulose hydrate, polyethylene and synthetic polymer, also used for Tetra Brick Aseptic production. The combination of materials is applied for specific barrier requirements. The film is firmly settled through a heat-sealing overwrap machine. This type of packaging is gas permeable, ensuring hygienic protection, without any improvement in the product shelf-life which is guaranteed by the cold chain. The shelf-life is approximately 3–4 days until off-odours, off-flavours and darkening are detectable [15]. *Pseudomonas* spp. and Enterobacteriaceae produce typical cheesy and sulphury putrefaction off-odours (acetoindiacetyl and 3-methylbutanol formation or hydrogen sulphide formed by Enterobacteriaceae, and dimethyl sulphide formed by *Pseudomonas* spp.) [26–29].

The myoglobin in its ferrous oxygenated form is the key factor for meat colour's stability. The initial red colour is caused by the oxygenation of myoglobin in oxymyoglobin (cherry-red colour), but slowly, during the storage, the myoglobin is oxidised to ferric (Fe^{3+}) metmyoglobin, which is responsible for the brown colour. Another cause of detriment is lipid oxidation determining meat rancidity [12,30–32].

3.2. Modified Atmosphere Packaging

The technique of reducing the oxygen concentration in the package is defined as Modified Atmosphere Packaging (MAP) and involves the replacement of air with a gas or a mixture of gases.

Vacuum packaging (VP), controlled atmosphere packaging (CAP) and modified atmosphere packaging (MAP) sensu stricto compose this category. The gas changes depend on the respiration rate of the food product and permeability of the film [33].

The purpose is to create a condition which lags the microbiological, biochemical and enzymatic activities in the food product, resulting in an extension of shelf-life, in association with a lesser use of additives. MAP was first recorded in 1927 and the effects were not only an increase in shelf-life, significant in association with refrigeration temperature, but also an enhancement in quality aspects such as colour stability or slice separation. The product is placed into a pack and the air is removed and replaced with a mixture of gases; then, the packaging is hermetically sealed [34]. The plastic films used for packaging in protective atmosphere must be high barrier (low permeability to oxygen and water vapour), resistant to mechanical stress and harmless from a chemical and sensory point of view. Other gases suggested include nitrous and nitric oxides, carbon monoxide, sulphur dioxide, ethane and chlorine, nevertheless most of these have not been developed for safety, legal aspects, consumer response or cost reasons. Oxygen, nitrogen and carbon dioxide are used in different combinations and proportions depending on the product, on the microbiological flora to be inhibited and on the colour stability requirements. Nitrogen (N_2) is added as filler inert gas to prevent pack collapse, and is also added to replace oxygen to prevent rancidity and inhibit the growth of aerobic bacteria [33]. For the last purpose mentioned, carbon dioxide has a major effect, increasing the lag phase and generation time of aerobic microflora, but the gaseous atmosphere created will select facultative anaerobic and anaerobic strains, in particular, lactic acid bacteria may grow abundantly.

Fresh meat is subjected to sensory deterioration by oxidation of myoglobin to metmyoglobin (browning) and the excessive proliferation of psychotropic microflora associated with proteolytic and lipolytic reactions, causing discolouration, viscous surface patinas and unpleasant odours. For processed meat products, the gas mixture commonly used is 20–30% CO_2 and 70–80% N_2. In case of fresh meat pieces to be packed in gas-proof packages instead of oxygen-permeable foil, the bright-red colour can be reached by adding oxygen to the gas mix to be injected. The use of carbon monoxide at low concentration determines the formation of carboxymyoglobin with a more stable cherry-red colour of meat [35] for a longer period compared with other packaging techniques [36].

Controlled atmosphere packaging (CAP): This type of packaging is associated with a real and constant control over the composition of the gas to guarantee an accurate maintenance of the predetermined gas percentages [12,31,32].

3.3. Vacuum Packaging

The vacuum packaging (VP) is a preservation method, which consists in the elimination of air. The process phases are composed by putting the product, previously cased in a specific bag, in a vacuum chamber equipped with a vacuum pump for the air extraction [37]. Actually, the equipment is not able to subtract 100% of air, but realistically, 75–85%, or a maximum of 90%, is eliminated from the pack. The main advantages of this technique are an increase in product shelf-life, protection of the food from external hazards and better handling. In case of fresh meat, the absence of oxygen determines the formation of metmyoglobin with progressive unattractive darkening of the product, so that the comprehensive appearance of the product may appear less pleasing for the consumer, negatively influencing its choices. Inside the vacuum pack, the gaseous phase is not steady during storage, characterised by a decrease of oxygen and an increase in the concentration of carbon dioxide, therefore with a progressive selection of a CO_2-tolerant microbiota. An additional method is the skin-type vacuum packaging in "Cryovac" bags, which allows vacuum packaging with a complete adhesion between the plastic material and the product: these bags are made of shrinkable plastic, immerged at 90 °C for a few seconds in warm water, becoming completely adherent to the product [15].

There is a huge variety of target products for the application of VP from raw meat to ready-to-eat products, whereas Cryovac is mainly used for Vienna sausages, cotechino and cooked ham. Advanced vacuum skin packaging consists of an instantaneous heating of an upper film at high temperature immediately before its application to the meat surface. High temperature inactivates part of the bacteria present on the surface and is described as a measure to extend shelf-life, and the close contact with the surface avoids air and wrinkles formation. This leads to an extended shelf-life and a slower growth of bacteria [38].

3.4. Functional Packaging

There are two distinct types of functional packaging: the active packaging, which interacts with the atmosphere inside the package and with the food by the release of substances (i.e., preservatives, antioxidants), and the intelligent packaging, which requires the use of an internal or external indicator on the package which provides product information (time-temperature indicators, indicators of oxygen and carbon dioxide).

3.4.1. Active Packaging

Active packaging consists of an interaction between the package and the food system, acting directly with the product or the headspace. In particular, antimicrobial food packaging acts to decrease, inhibit or delay the growth of microorganisms, which may be present in packed food or packaging material itself. The forms used for this kind of packaging may consist in the addition of sachets pads, including volatile antimicrobial compounds into packages, incorporation of volatile and non-volatile antimicrobial molecules directly into polymers, coating or adsorbing antimicrobials onto polymer surfaces or immobilisation of antimicrobials to polymers by covalent or ion linkage [39]. The application of antimicrobial packaging in food is aimed at extending the shelf-life and promoting safety by reducing the growth rate of specific microorganisms through direct contact with the product surface.

3.4.2. Antimicrobial Packaging

Chitosan is a cationic polymer coming from partial deacetylation of chitin on the exoskeleton of crustacean and insects. On the external part, films made of chitosan have some aminic groups, positively charged, that interact with the negative counterpart of the membrane cell, favouring the cell adhesion to the film, loss of intracellular material and death of microorganisms [11].

Active and intelligent packaging, in the field of materials and articles intended to come into contact with food, are those capable of interacting with the food contained therein. The former aim to improve the conservation of the products, the latter to communicate any critical issues in this regard.

Active packaging absorbs or releases substances, in the product or in the environment where it is located. The first example is the modified atmosphere preservation technology, which is carried out with a mixture of inert gases (nitrogen, carbon dioxide and oxygen), placed and kept in the primary packaging and hermetically sealed in order to inhibit microbial proliferation and extend the shelf-life of perishable products. Regulation 1333/2008, Annex I, pint 20, stipulates: "'packaging gases' are gases other than air, introduced into a container before, during or after the placing of a foodstuff in that container" [40]. Article 2.2.a of the Regulation 1935/2004 stipulates that: "active food contact materials and articles (hereinafter referred to as active materials and articles) means materials and articles that are intended to extend the shelf-life or to maintain or improve the condition of packaged food. They are designed to deliberately incorporate components that would release or absorb substances into or from the packaged food or the environment surrounding the food" [41].

Absorbent materials are widely used in numerous applications:

- Oxygen absorbers (in bags, trays and containers), by absorbing the oxygen inside the package, inhibit the growth of microorganisms (e.g., mould, yeasts) and slow down the oxidation processes of food. Some of them also release bacteriostatic substances, such as ethanol.

- Ethylene absorbers: a substance that is naturally present in plants, responsible for their maturation and deterioration.
- Moisture absorbers (super-absorbent materials generally placed on the bottom of the meat and fish trays) trap the liquid released from the food and thus inhibit the proliferation of microorganisms.

Anti-bacteria and anti-mould films are now one of the liveliest fronts in the development of active packaging. The presence of substances with antibacterial properties—such as chitosan (extracted from the exoskeleton of crustaceans), tea tree oil, alginates (extracted from marine algae), cinnamon and thyme oils and ethanol—inhibits the proliferation of microorganisms and are particularly effective in direct contact with baked goods and other foods with appreciable moisture content [42].

Smart (or intelligent) packaging is used to keep food storage conditions under control, like ripeSense (http://www.ripesense.co.nz), a microscopic sensor that (measuring the amount of ethylene inside the packaging) shows the degree of ripeness of the fruit with a chromatic gradation that varies and is visible on the label.

Regulation CE 1935/04, article 2.2.b, stipulates: "intelligent food contact materials and articles (hereinafter referred to as intelligent materials and articles) means materials and articles, which monitor the condition of packaged food or the environment surrounding the food" [41].

The time temperature indicators (TTI) show the freshness level of the product and its actual suitability for the intended use on the label. Their application on products intended for the final consumer is very scarce, since no one has an interest in revealing to the public (nor to the control authorities) the recurring critical issues in the storage of food in the logistics and distribution phases, two critical issues that relate in particular to the discontinuity of the cold and frost chains [42].

Regulatory authorities, it is worth mentioning, should have issued regulations on temperature control. But these regulations, probably due to the lack of interest of producers, have never been adopted.

4. Packaging and Microbiology

The safety and the stability of foods depend on the microorganisms present on food at the packaging step. Many factors affect the microorganisms' growth in food and are defined as intrinsic and extrinsic of the substratum [8]. The main factors which favour some bacterial strains instead of others and influence the shelf-life of meat products are packaging (aerobically, vacuum or modified atmosphere), the composition of products (presence of fat, NaCl content, a_w, pH), storage temperature and other factors such as antibacterial substances or biopreservatives [43,44]. The spoilage flora detectable on meat is influenced by packaging conditions and gaseous composition of the atmosphere surrounding the product [26,45]. Aerobic storage conditions promote the growth of aerobic strains: *Pseudomonas* spp. finds the optimal growth conditions and, in particular, *Pseudomonas fragi* is the most frequently isolated strain as it is able to use creatine and creatinine as substrates [45]. In the first period of shelf-life, *Brochotrix thermosphacta* is the dominant species, but *Pseudomonas* spp., *Acinetobacter* spp. and *Moraxella* spp. are considered the main spoilage responsible in aerobically stored meat products at a wide range of storage temperatures (−1 to 25 °C). Strains of the *P. fluorescens* group and psychotropic *P. fragi*, *P. ludensis* and *P. putida* are frequently isolated from aerobically packed spoiled meat [46,47]. Reaching a concentration of 10^7 cfu g^{-1}, *Pseudomonas* growth on meat determines the formation of slime and off-odours, especially when the nitrogenous compounds' metabolisms prevail over carbohydrates fermentation. *Shewanella* is a genus closely related to *Pseudomonas* and contributes appreciably to spoiling food: in chill-stored vacuum-packaged (VP) meat and high pH VP meat, *S. putrefaciens* is one of the predominant spoilers [8,13,27,29,48–51]. Meat from different species can be packaged under vacuum. Microbiologically, the effects are a general inhibitory action and a selective action. The oxygen absence determines the inhibition on aerobic strains, with a longer lag phase and a slower growth rate. The suppression of *Pseudomonas* spp. is almost total, and lactic acid bacteria prevail, inhibiting the growth of Enterobacteriaceae. Refrigeration temperature should be respected. The anaerobic conditions prevent the growth of many species cited responsible for microbial spoilage in aerobic packaging, and the oxidation of lipids, which is catalysed by oxygen and provokes discolouration and off-odours. On the other side, the vacuum packaging selects the development of anaerobic microbial flora (pathogens, i.e., *Cl. perfringens* and *Cl. Botulinum*, but also non-pathogenic strains, such as lactic acid bacteria homo- and hetero-fermenting). Lactic acid bacteria dominate vacuum packaging, in particular *Carnobacterium* spp., *Lactobacillus* spp. and *Leuconostoc* spp.

Packaging of meat under vacuum or CO_2-modified atmosphere has resulted in extended shelf-life compared with traditional packaging conditions [52]. The use of CO_2 and N_2 extends the lag phase of aerobic microorganisms and promotes the growth of facultative and anaerobic species. This change in packaging conditions determines a shift from aerobic bacteria, such as *Pseudomonas* spp., to facultative anaerobic species, such as *Brochotrix thermosphacta* [43] and lactic acid bacteria (LAB) [48]. Lactic acid bacteria are the predominant microflora of vacuum or CO_2-modified atmosphere packaging, representing dominant spoilage-causing bacteria [33,53]; in fact, the combination of micro-aerophilic conditions (0.8% O_2) and a reduced a_w inhibits Gram-negative spoilage flora and favours proliferation of LAB [26,54]. In addition, the headspace composition in modified atmosphere packaging (MAP) conditions is dynamic, with CO_2 dissolving in meat and being formed by tissue and bacterial consumption of O_2 [47]. Among Enterobacteriaceae, *Serratia* spp. is the most common genus isolated from MAP meat [48]. The strict aerobes are easily devitalised (*Pseudomonas* spp., Gram-negative bacteria and moulds), while anaerobes (*Clostridium* spp., *Listeria* spp., lactic acid bacteria) can survive.

5. Meat Quality and Meat Colour

Concerning meat quality parameters, the most used colour system is the so-called CIE Lab, where lightness (L*) is a measure of total light reflection on a scale ranging from 0 (black) to 100 (white), redness (a*) indicates the colour change from red to green and the yellowness (b*) indicates the colour change from blue to yellow [55]. In the aerobic packaging, ground beef shows an L* value higher the first day of storage, which decreases during the subsequent days; for foal meat, L* increases during storage while a* decreases for the metmyoglobin formation [25]; for swine meat, L* trend is increasing, b* is higher from the fourth day of storage, a* is constantly decreasing, while pH stands at around 5.45 ± 0.08 [56].

The lipid oxidation is a cause of meat detriment and is calculated as TBARS (thiobarbituric acid reactive substances), with a progressive increase during storage [25,34,56]. The same effect is due to proteins' oxidation, evaluated through carbonyl detection and diminution of sulfhydryls [56].

In MAP packaging, O_2 binds myoglobin on the surface of the product, forming oxymyoglobin, which determines the 'fresh' bright red colour appreciated by consumers. Elevated O_2 concentration causes an increase of a* in various meat in the early days, the first 3–4 days for beef and 4–6 days for pork, then it decreases, whereas the b* value increases from the 3rd–4th days [15]. Regarding other parameters, the TBARS content is significantly increasing, and in less than three days, exceeds the value of freshness of the meat, metmyoglobin rises during the storage time and the activities of antioxidant enzymes in the beef decrease [57]. When O_2 is less than 0.5% of total gas, the meat colour will change to brown/grey for the formation of metmyoglobin, as happens for vacuum packaging [57].

In vacuum packaging, TBARS increase during storage in the beef and in the dry-cured pork neck [57]. Concerning L*, a slight increase was described in the early days in pork, instead, in lamb and beef, a progressive decrease has been described [57]. A special case was described by Rubio [37] that evaluated the presence of a white film on the surface of the cured pork neck and the Cecina de Leon, which determined an increase of L*.

The maturation of fresh bovine meat under vacuum is appreciated, positively influencing tenderness and meat taste. Also, processed meat (salami, cured meat products, smoked meat) can be packaged under vacuum, in this case, the maintenance of the colour is preserved and the occurrence of moulds and spoiling microorganisms is avoided. Nowadays, vacuum is also an alternative in case of sliced cured meat products in the markets. Some products are cooked after packaging, according to two typologies: cook in–strip off (cooking under vacuum followed by opening of the pack to get rid of produced liquid, and transfer to the final pack) or cook in–ship in (after cooking, the vacuum pack is directly sold). In this procedure, water does not reach 100 °C and thermos-sensible nutritional components are preserved. In case of meat and meat products, this technique avoids the occurrence of holes and cracks. Slices are more compact and softer compared to traditional cooking. Cooking is done at temperatures between 70 and 100 °C.

6. Discussion

Foods are dynamic systems with a very limited shelf-life, and subsequently, the packaging requirements are different from the ones linked to inert products. The chemical, sensory and microbiological meat characteristics are progressively modified during the product shelf-life; the phenomenon is unavoidable, but packaging could furnish a technological response to slow this process. Chemical alterations which compromise food quality are enzymatic browning and non-enzymatic hydrolysis, oxidation of lipids and proteins, protein denaturation, hydrolysis of mono and polysaccharides and degradation of the pigments. To limit these chemical reactions, packaging could avoid water vapour losses (primarily from the food to environment) thanks to barrier properties. Microbial growth can be reduced by controlling the variation of influencing factors, such as a_w, pH and the migration of nutrients. Since the chemical and physical alterations do not occur independently from each other, by controlling the chemical reactions and microbial growth, physical stability is better maintained

Antimicrobial packaging can play an important role in extending the meat shelf-life and reducing the risk of pathogen contamination, but it should never substitute the requisite of good-quality raw materials, properly processed foods and good manufacturing practices. This type of packaging could be integrated in the hurdle technology, as part of a composite system for achieving food safety.

Consumers continue to demand foods minimally processed and with fresh-like qualities, whereas modern distribution systems require an adequate shelf-life. Numerous types of food packaging can be used in combination with food preservation approaches in order to amplify the effectiveness of the food preservation chain [58].

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