Chapter

Lipid Peroxidation in Meat and Meat Products

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Abstract

The meat and meat products present a considerable amount of lipid in their composition. The lipid composition of these foods is diversified. Thus, depending on the type of meat, which can be rich in unsaturated fatty acid, there is an increase in the disposition for lipid oxidation. Oxidation reactions not only reduce the shelf life and nutritional value of food products but also can generate harmful compounds. Thus, having in view that many types of new technologies are applied to these foods, the proposal of this chapter of how these new methodologies have affected the lipid peroxidation of these foods. Moreover, the aim is to evaluate what impacts on the chemical characteristics of these foods.

Keywords: fatty acids, rancidity, meat preservation, high pressure, microwave heating, ultraviolet light, infrared heating, radiation

1. Introduction

Oxidation is one of the essential factors in the nonmicrobial degradation of meat and meat products. Thus, the lipid oxidation has been extensively investigated in these foods because the products of the reaction can readily react with proteins, leading to sensory modifications and the loss of nutritional value [1].

Food preservation is a process to extend the shelf life of foods while maintaining their safety and sensory properties. Nowadays, some new preservation techniques are being developed to satisfy the current demands for more efficient preservation and higher consumer satisfaction about nutritional and sensory aspects, convenience, safety, absence of chemical preservatives, low price, and environmental safety [2]. These methods include high-pressure processing, microwave heating, ultraviolet light, infrared heating, and radiation.

The high-pressure processing (HPP) is considered a food safety process that can stabilize meat by inactivating microorganisms. However, HPP can favor the lipid peroxidation by promoting the formation of radicals [1].

In the microwave heating processing, changes associated with chemical components of food products relate mainly to the cooking loss, antioxidant activity, bioactive components, and lipid peroxidation. During microwave cooking, protein denaturation, cooking loss, and lipid peroxidation of meat and meat products increase with the increase in heating time or temperature [3].

Another technique entirely used in research is the infrared cooking that consists of the penetration of electromagnetic waves to the food material. The absorbed infrared waves could cause electromagnetic vibrations and result in temperature increase within the food material. The penetration capacity of infrared waves limits the whole cooking of food material [4]. This technology is of particular interest to the processed meat sector, since conventional cooking ovens using high-velocity hot air convection can cause overheating, oxidation, charring, impingement damage, low yield, difficult emissions, as well as high energy costs. Infrared radiation has intrinsic advantages such as having no direct intention or necessity to heat the air, keeping oven temperatures and humidity at low values. A further advantage of this method is the ease with which heat can be applied evenly over a broad surface area [5].

Radiation from ultraviolet light C (UV-C) also has been demonstrated as a potential surface decontamination method in addition to several advantages over regular sanitation methods. However, UV-C radiation possibly affects the physicochemical properties of meat products [6]. Paskeviciute et al. [7] used the UV-C for decontamination of chicken from food pathogens and observed small changes in the intensity of lipid peroxidation (0.16 mg malondialdehyde per kilogram of chicken meat). Moreover, these authors reported that sensory properties of treated chicken did not have changes of raw chicken, chicken broth, or cooked chicken meat when treated under nonthermal conditions in comparison with control.

Finally, the food radiation is one of the nonthermal methods of meat preservation. It is the process of exposing the food, either in the package or in bulk, to controlled amounts of ionizing radiation to achieve a purpose such as the extension of shelf-life, insect disinfection, the elimination of food-borne pathogens, and parasites [8]. It is considered a more effective and appropriate method to enhance food stability and safety when compared to other processing methods like heat and chemical methods. Also, it does not reduce significantly the nutritional and the sensory quality of food at lower doses. According to Fallah et al. [9], gamma irradiation had no significant effect on the primary sensory attributes of the irradiated samples of ready-to-cook Iranian barbecued chicken. Moreover, at the end of the storage period of 15 days, the irradiated samples had more sensory acceptance than nonirradiated samples.

Therefore, considering that most of the new technologies mentioned increase lipid peroxidation, strategies have been adopted to reduce this process. Among the measures adopted, include vacuum packaging and use of antioxidants [10].

2. Lipid composition in meat and meat products

Meat lipids are mainly composed of triglycerides (correspond to about 95% of meat lipids) and phospholipids, which contain saturated fatty acids, monounsaturated fatty acids (MUFAs), and polyunsaturated fatty acids (PUFAs). Triglycerides are storage lipids and are composed of three fatty acids esterified to glycerol and have more ratios of saturated fatty acids. The phospholipids are often functional lipids prevalent in cell membranes and as such contain more PUFA than triglycerides [11]. The main unsaturated fatty acids present in meat lipids have one or two double-chain linkages. The most common is the monounsaturated oleic acid (C18:1), which corresponds to about 40% of the fatty acids in beef. The two main PUFAs, linoleic (LA, C18:2 n − 6) and linolenic (C18:3 n − 3), form a substantial part of the membrane lipids but also form part of the storage lipids [12].

The firmness fat meat depends on the amount of saturated fatty acids. In general, the cattle fat is more saturated than those of pigs, and these are more saturated than those of poultry. Thus, the saturated fatty acids content explains the higher hardness of fat in this sequence, cattle > pigs > poultry. The melting point of cattle fat is between 43 and 47°C, while that of pigs is between 38 and 44°C and that of poultry is between 31 and 37°C [13].

According to Wood et al. [14], the fatty acid composition of adipose tissue and muscle in pigs, sheep, and cattle depends on the amount of fat in the carcass and

	Adipose tissue			Muscle		
	Pigs	Sheep	Cattle	Pigs	Sheep	Cattle
14:0	1.6[a]	4.1[b]	3.7[b]	1.3[a]	3.3[c]	2.7[b]
16:0	23.9[b]	21.9[a]	26.1[c]	23.2[b]	22.2[a]	25.0[c]
16:1 cis	2.4[a]	2.4[a]	6.2[b]	2.7[b]	2.2[a]	4.5[c]
18:0	12.8[a]	22.6[b]	12.2[a]	12.2[a]	18.1[c]	13.4[b]
18:1 cis – 9	35.8[b]	28.7[a]	35.3[b]	32.8[a]	32.5[a]	36.1[b]
18:2 n – 6	14.3[b]	1.3[a]	1.1[a]	14.2[b]	2.7[a]	2.4[a]
18:3 n – 3	1.4[c]	1.0[b]	0.5[a]	0.95[b]	1.37[c]	0.70[a]
20:4 n – 6	0.2	ND	ND	2.21[b]	0.64[a]	0.63[a]
20:5 n – 3	ND	ND	ND	0.31[b]	0.45[c]	0.28[a]
n – 6:n – 3	7.6	1.4	2.3	7.2	1.3	2.1
P:S	0.61	0.09	0.05	0.58	0.15	0.11
Total	65.3	70.6	70.0	2.2	4.9	3.8

Means with different superscripts ([a], [b], and [c]) are significantly different ($p < 0.05$).

Table 1.
Fatty acid composition (g/100 g fatty acids) and content (g/100 g total fatty acids in subcutaneous adipose tissue and muscle) of loin steaks/chops in pigs, sheep, and cattle [15].

muscle. **Table 1** shows that adipose tissue has a much higher fatty acid content than muscle, but the fatty acid composition of the two tissues is broadly similar. However, there are significant species differences. Pigs have much higher proportions of the polyunsaturated fatty acid (PUFA) linoleic acid (18:2 n − 6) in both tissues than cattle and sheep.

The linoleic acid (18:2 n − 6) derives from the diet. In pig, it passes through the stomach to have changed and is then absorbed and incorporated from there into tissues. In ruminants, the fatty acids which are at high levels in concentrate feedstuffs are degraded into MUFAs in the rumen by biohydrogenation and only a small proportion, around 10% of dietary 18:2 n − 6, is available for incorporation into tissue lipids. In the sheep and cattle, the fatty acid is at higher levels in muscle than adipose tissue. The second most important PUFA is α-linolenic acid (18:3 n − 3), which is present in many concentrate feed ingredients but at lower levels than 18:2 n − 6. In pigs, the proportion is higher in adipose tissue than muscle. The linolenic acid is a primary dietary fatty acid for ruminants, since it constitutes over 50% of total fatty acids in the grass [13, 16, 17].

Greater incorporation of 18:2 n − 6 into pig muscle fatty acids compared with ruminants produces higher levels of 20:4 n − 6 by synthesis, and the net result is a higher ratio of n − 6:n − 3 PUFA compared with the ruminants (**Table 1**). Nutritional advice is for ratios <4.0 [18], and so pig muscle is unbalanced relative to that of the ruminants. On the other hand, the ratio of all PUFAs to saturated fatty acids (P:S), the target for which is 0.4 or above, is much higher, beneficially so, in pigs and other monogastrics compared with the ruminants [14].

Moreover, in beef, conjugated linoleic acids (CLAs) are produced in the rumen by biohydrogenation at a level of approximately 1.2e10 mg per g of fat, which results in approximately 36 mg of linoleic acid per g of fat [19, 20]. Studies reported that minced meat (15% lipids) had an average content of 120 mg CLA per 100 g of steak. Moreover, the animal's diet can influence the CLA content of beef meat [1].

3. Lipid peroxidation in meat and meat products

The lipid peroxidation is a primary reason for the deterioration of meat and meat products, giving undesirable odors, rancidity, texture modification, loss of essential fatty acids, or toxic compound production. Moreover, lipid oxidation products implicate several human pathologies (atherosclerosis, cancer, inflammation, or aging processes) [21, 22].

Lipid peroxidation generally involves the degradation of polyunsaturated fatty acids (PUFAs) and the production of secondary decomposition products, including carbonyls and hydrocarbon compounds. The oxidative stability of meat depends on the balance of anti- and pro-oxidants and the composition of oxidizable substrates, including PUFAs, cholesterol, proteins, and pigments [23–26].

The peroxidation reaction of PUFA in biological tissues can be initiated by free radicals, which are present in animal cells with active metabolic processes. After the slaughter animals, their muscle cells become overloaded with pro-oxidants, peroxidized lipids, and oxygen radicals. These changes also occur during storage at 2–4°C. The secondary phase of lipid peroxidation should occur immediately after slaughtering and occurs during the early postslaughter phase. The biochemical changes, which accompany the conversion of muscle to meat, generate conditions in which the oxidation in the highly unsaturated phospholipid fraction of subcellular membranes is no longer tightly controlled [27, 28].

Malondialdehyde (MDA), which is a three-carbon compound formed after the scission of peroxidized PUFAs, is one of the main products of lipid peroxidation. Consequently, there is the aldehydes production in substantial quantities during lipid oxidation, and therefore, these compounds are candidates for reactions with thiobarbituric acid (TBA). Consequently, the detection of these secondary products through chemical or instrument methods is relevant in studies examining lipid peroxidation in meat and meat products [29–31].

Many methods have been proposed for evaluating the MDA content in meat as a marker of lipid oxidation. High-performance liquid and gas chromatographic methods offer better specificity and sensitivity when detecting malondialdehyde. However, spectrophotometric methods are preferable during routine analyses of large samples due to their simplicity and low cost [32, 33]. The TBA test is the most common method used to quantify lipid oxidation products through the determination of MDA [34].

4. New technologies for preserving meat products and their impacts on lipid stability

More than two decades ago, novel food processing technologies that based on high tech or cutting-edge advances started to emerge to address productivity issues, extending product shelf life without affecting the nutritional content, sensory attributes, and product specifications. In research performed with food professionals from industry, academia and government observed that technologies such as high-pressure processing, microwave heating, ultraviolet light, infrared heating, and radiation were scored well for implementation or potential implementation in meat sector [35].

High-pressure processing (HPP) is also called high hydrostatic pressure processing, pascalization, or high-pressure pasteurization. This technology effectively inactivates vegetative bacteria, yeast, and molds using pressures up to 600 MPa at ambient temperature and can inactivate spores when combined with high temperature (high-pressure thermal processing). Moreover, the HPP retains most of the sensory and nutritional characteristics of solid or chilled products. Its effect on enzymes is variable [36–38].

HPP treatment, when used in meat, can promote peroxidation reactions, and it is essential to control the balance between pro-oxidants and antioxidants to prevent this phenomenon. Thus, many researchers have been interested in evaluating the extent of oxidation in pressurized meat to understand the underlying mechanisms. In particular, the fate of proteins such as myoglobin and hemoglobin under high-pressure treatment has been investigated because these proteins act as pro-oxidants in raw meat [1].

Studies concluded that treatment at pressures above 350 MPa has a pro-oxidant effect for all types of meat [38–44]. Moreover, the lipid peroxidation levels have been evaluated during storage after HPP treatment. After treatment at pressures between 300 and 800 MPa, the TBARS values increased in chicken meat kept at 5°C for 14 days, mainly when used at more than 400 Mpa [45]. Similar results were reported for beef pressurized at between 200 and 600 MPa for 20 min and kept refrigerated for 7 days [41].

The lipid peroxidation in meat products, such as dried products, is different than it is for raw or cooked meat due to the postprocessing operations and the longer conservation time. If HPP provides a prooxidant impact on meat products, this effect can be stressed by the subsequent storage [46]. Thus, the difference in the oxidative stability of dry-cured Iberian ham after 39 days of refrigerated storage for slices that had been pressurized at 400 MPa was observed. Treatment at 400 MPa led to discoloration of the products [47]. Moreover, HPP treatment of dry-cured loin after ripening affected its quality. However, using vacuum storage minimized the differences [39].

Thus, the extent of lipid peroxidation depends on the treatment duration, the temperature of the HPP treatment, and mainly on the type of meat or meat product. The beef seems to oxidize less than other types of meat. Furthermore, the initial packaging of the treated sample has a significant impact on the meat's peroxidation during the HPP treatment. Indeed, vacuum packaging, which is most frequently used for HPP treatment, reduces the impact of the pressure on the peroxidation process [42, 48, 49].

The microwave heating refers to the use of electromagnetic energy at the particular frequencies of 915 and 2450 MHz to generate heat in food. Contrary to conventional thermal techniques, heat is generated volumetrically throughout the product at faster rates. It can be used on solid foods [36, 37].

According to Byrnea et al. [50], for the control oxidation of any given lipid, the most critical parameters are the thermal treatment conditions (temperature and time of cooking). The lower temperature of cooking could reduce energy consumption, but a final internal temperature of 65–85°C must be reached to ensure safety [51]. Das and Rajkumar [52] evaluated the effects of various fat levels (5, 10, 15 and 20%) on microwave cooked goat meat patties. Each patty was cooked by microwave (700 W, 2.45 GHz) to an internal temperature of 75–80°C. Microwave cooking time was found to decrease with an increase in fat level, as the dielectric constant and loss factor decrease with fat content. Also, a sample with high-fat content might possess a lower specific heat capacity, which might lead to a decrease in the heating rate. The product yield (i.e., ratio of cooked weight to the raw weight) was found to be significantly lower for 20% fat level due to high total cooking loss (15.2%). Thus, the amount of fat content in food materials influences the microwave heating regarding heating rate, uniformity of temperature distribution, and fat retention [53].

Serrano et al. [54] reported that cooking methods, such as microwaves and conventional oven, did not increase TBARs values in restructured meat products. However, Dominguez et al. [55], comparing different cooking methods (roasting, grilling, microwaving, and frying) in the foal meat, observed that all the cooking methods increased TBARs content since high temperature during cooking causes increased oxidation in foal steaks. This increase was higher when foal steaks were microwaved or roasted. Therefore, many factors are influencing the lipid peroxidation when used in this technology.

The ultraviolet light-C (UV-C) produces nonionizing radiation with germicidal properties at wavelengths in the range of 200–280 nm. It can be used for surface treatment and as a nonthermal alternative [56, 57]. Different from thermal processing, this nonthermal technology reduces the microbial load without significantly changing the nutritional and sensory characteristics of meat products [58].

The beneficial effect of UV-C light on chicken meat was evaluated by many authors [59, 60]. These authors reported that UV light efficiently decreased the pathogenic bacterial load on the carcass surface without negatively affecting carcass color or meat lipid oxidation. On the other hand, Koutchma et al. [61] observed that UV light potentially affects food products due to free radical generation via a wide variety of organic photochemical reactions. Possible undesirable effects include oxidation of vitamins, lipids and proteins, degradation of antioxidants, changes in texture and color, and formation of off-flavors and aromas.

Lazaro et al. [6] evaluated three levels of UV-C intensities (0.62, 1.13, and 1.95 mW/cm^2) for up to 120 s in chicken breast. These authors reported that the intensity of 1.95 mW/cm^2 decreased the levels of pathogenic bacteria and can be used as a nonthermal technology to improve the superficial quality of packed poultry meat without promoting relevant changes on some quality indicators.

Infrared heating (IR) refers to the heating of materials by electromagnetic radiation having a wavelength of 1.3–4.0 μm (infrared radiation). This technique is based on the ability of materials to absorb a specific part of the spectrum of such radiation. Deep or superficial heating of the irradiated body, as well as local drying without heating the entire object, may be accomplished with appropriate selection of the emission spectrum of infrared radiation [62].

Shorter wavelength radiation penetrates the surface of meat and meat products more efficiently probably because of the preferential absorption spectrum of water in the surface. However, as the surface dries, this mechanism soon becomes less effective. Because of the higher fat content of the surface of the meat product samples, a higher proportion of the available infrared radiation from a far infrared source will be absorbed [5]. For the characteristics of the meat and meat products, the rapid action of surface heating provided by this method retains internally, flavor, aroma, and moisture, occurring changes only in the surface components, which may favor the Maillard reaction [63].

Turp et al. [64] evaluated the influence of final infrared cooking on characteristics of ohmically precooked meatballs. These authors concluded that infrared cooking, which is mainly useful for surface heating, can be applied as a final cooking method to improve the quality characteristics of ohmically precooked beef meatballs. Moreover, according to the same authors, the intensity of the infrared energy is affected by both the power applied and the distance between the infrared source and the meatball surface. Since the application of the different infrared intensities changes the total heat generation on the meatball surface, the temperature increase can vary.

The radiation technology includes irradiation by any of the three sources: gamma-rays, X-rays, or electron beams. They are often also referred to as ionizing radiations. Gamma rays can penetrate the food, but electron beams have a limited penetration depth [65, 66].

The radiation provides the production of free radicals, which could cause the changes in food components, such as the lipids and proteins in meat. Therefore, although radiation is a very useful cold sterilization technique, its utilization in meat or meat products has provided these problems. Studies have demonstrated that many chemical changes and quality changes in radiated meat were associated with free radical reactions, such as lipid and protein oxidation, which consequently caused the odor and color changes of meat [67]. Jo and Ahn [68] suggested that the lipolysis and lipid oxidation by the radiation played the critical role in the off-odor formation of irradiated meat.

Irradiation-induced oxidative chemical changes are dose dependent, and the presence of oxygen has a significant effect on the rate of oxidation of lipids and myoglobin in the muscle system [69]. Kim et al. [70] reported that no significant changes in the thiobarbituric acid reactive substances values (TBARS) of dry fermented sausages irradiated at 2 and 4 kGy during refrigerated storage. However, Kang et al. [71] showed that the levels of TBARS in irradiated half-dried seafood products increased as the dose was increased (from 3 to 10 kGy).

5. Strategies to reduce lipid peroxidation

For reduction of lipid peroxidation in meat and meat products, the antioxidant compounds have been added to products derived directly or, in some cases, incorporated into the diet of the animals. In recent years, special attention has been paid to some medicinal plants that could be used as potential sources of antioxidants for meat and meat products preservation and nutritional quality improvement. Most of the plant materials (herbs and spices) possess relatively high chemical nutrients (such as protein, fat, and carbohydrate), mineral contents (calcium, potassium, iron, phosphorus), and less anti-nutritional properties [72].

Pindi et al. [73] reported that *Kappaphycus alvarezii* (edible seaweed rich in polyphenolic substances) added in sausages reduced the lipid oxidation this poultry product during storage for 12 days at the 4°C. Panda and Cherian [74] reported that extracts of *Artemisia annua* (20 g. kg^{-1}) added in the broiler diets were useful in the lipidic oxidation delay of the poultry meat.

Bolumar et al. [75] evaluated the effect of the use of active antioxidant packaging for chicken meat processed by high-pressure treatment. For this, patties made of minced chicken breast and thigh packed in standard vacuum-packaging or active antioxidant packaging were subjected to high-pressure treatment (800 MPa, 10 min, 5°C) and subsequently stored for 25 days at 5°C. Lipid oxidation was studied at the surface and the inner parts of the meat patties. These authors observed that lipid oxidation was higher in the surface part, and the active packaging was able to delay it up to 25 days. The lipid oxidation was limited in the inner part of the meat patties and restrained at the surface of the active packaging.

According to Brewer [10], the methods to decrease the detrimental effects of irradiation include oxygen exclusion (vacuum packaging), replacement with inert gases (nitrogen), and the addition of protective agents (antioxidants).

Thus, Badr and Mahmoud [76] assessed the antioxidant effect of carrot juice in gamma-irradiated beef sausage. These authors observed that carrot juice significantly decreased the oxidative processes in the samples proportionally to the juice's concentration. Furthermore, the sausages that were formulated with carrot juice had a high acceptable sensory score as compared with the control samples.

6. Conclusions

Most of the methodologies used for the preservation of meats and meat products provide an increase in lipid peroxidation. The lipid peroxidation is one of the major factors limiting the quality and acceptability of meats and meat products. Among the technologies more promising to be used in meat and meat products has highlight the high-pressure processing, microwave heating, ultraviolet-light, infrared heating, and ionizing radiation.

For the high-pressure processing, studies have shown that this technology has a negative impact on lipid oxidation. This impact is generally limited by the antioxidants in the meat and by vacuum packaging.

Microwave heating of meat and meat products needs to be carried out to a great extent at a pilot scale level than at laboratory conditions so that the results might be useful for industrial applications. Despite the complex nature of microwave-food interactions, more research needs to be carried out for a better understanding of the process. Microwave heating products have the advantages of retaining more taste, color, quality, and nutritional value compared to those cooked by other conventional methods. This process is affected by the presence of moisture and fat content in food. Thus, in the literature, there are results which found increase or reduction in the lipid peroxidation depending on meat and meat product type, among others factors.

The ultraviolet-light is one such nonthermal technology that is approved for surface treatment of food, being an alternative surface decontaminant to be used for inactivating bacteria and viruses. Though with some limitations, if complemented with other processing techniques, this technology can help in better food preservation with minimal effects on the food quality.

Infrared heating offers many advantages over convection heating, including higher energy efficiency, heat transfer rate, and heat flux that results in time-saving as well as increased production line speed. This technology is attractive primarily for surface heating applications. In order to achieve energy optimum and efficient practical applicability of IR heating in the food processing industry, a combination of IR heating with microwave and other common conductive and convective modes of heating holds great potential.

The effects of ionizing radiation on meat could be reduced by various combinations of preslaughter feeding of antioxidants to livestock, the condition of the meat before irradiation (pH, oxymyoglobin vs. metmyoglobin), the addition of antioxidants directly to the product, gas atmosphere vacuum, packaging and temperature control.

Conflict of interest

There is no conflict of interest.

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