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
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 \(\text{n}^{-6}\)) in both tissues than cattle and sheep. The linoleic acid (18:2 \(\text{n}^{-6}\)) 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 feeds are degraded into MUFAs in the rumen by biohydrogenation and only a small proportion, around 10% of dietary 18:2 \(\text{n}^{-6}\), 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 \(\alpha\)-linolenic acid (18:3 \(\text{n}^{-3}\)), which is present in many concentrate feed ingredients but at lower levels than 18:2 \(\text{n}^{-6}\). 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 \(\text{n}^{-6}\) into pig muscle fatty acids compared with ruminants produces higher levels of 20:4 \(\text{n}^{-6}\) by synthesis, and the net result is a higher ratio of n \(-\text{6}\) to n \(-\text{3}\) 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].

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].

| Fatty acid    | 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\(^b\) | 2.7\(^b\) |
| 16:0          | 23.9\(^b\) | 21.9\(^a\) | 26.1\(^c\) | 23.2\(^b\) | 22.2\(^a\) | 25.0\(^a\) |
| 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\(^b\) | 22.6\(^c\) | 12.2\(^a\) | 12.2\(^a\) | 18.1\(^a\) | 13.4\(^a\) |
| 18:1 cis – 9  | 35.8\(^b\) | 28.7\(^b\) | 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\(^a\) | 1.0\(^a\) | 0.5\(^a\) | 0.95\(^b\) | 1.3\(^b\) | 0.70\(^a\) |
| 20:4 n – 6    | 0.2    | ND     | ND     | 2.2\(^b\) | 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 (\(p < 0.05\)).
Lipid Peroxidation

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/cm²) for up to 120 s in chicken breast. These authors reported that the intensity of 1.95 mW/cm² 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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References

[1] Guyon C, Meynier A, Lamballerie M. Protein and lipid oxidation in meat: A review with emphasis on high pressure treatments. Trends in Food Science and Technology. 2016;50:131-143

[2] Rahman MS. Food preservation and processing methods. In: Ahmed J, Rahman MS, editors. Handbook of Food Process Design. New York: Blackwell Publishing; 2012. pp. 1-17

[3] Guo Q, Sun D-W, Cheng J-H, Han Z. Microwave processing techniques and their recent applications in the food industry. Trends in Food Science and Technology. 2017;67:236-247

[4] Kor G, Icier F. Thermal imaging during infrared final cooking of semi-processed cylindrical meat product. Infrared Physics & Technology. 2016;79:242-251

[5] Sheridan P, Shilton N. Application of far infra-red radiation to cooking of meat products. Journal of Food Engineering. 1999;41:203-208

[6] Lazaro CA, Conte-Junior CA, Monteiro MLG, Canto ACVS, Costa-Lima BRC, Mano SB, et al. Effects of ultraviolet light on biogenic amines and other quality indicators of chicken meat during refrigerated storage. Poultry Science. 2014;93:2304-2313

[7] Paskeviciute E, Buchovec I, Luksiene Z. High power pulsed light for decontamination of chicken from food pathogens: A study on antimicrobial efficiency and organoleptic properties. Journal of Food Safety. 2011;31:61-68

[8] Shah MA, Mir SA, Pala SA. Enhancing food safety and stability through irradiation: A review. Journal of Microbiology, Biotechnology and Food Sciences. 2014;3:371-378

[9] Fallah AA, Saei-Dehkordi SS, Rahnama M. Enhancement of microbial quality and inactivation of pathogenic bacteria by gamma irradiation of ready-to-cook Iranian barbecued chicken. Radiation Physics and Chemistry. 2010;79:1073-1078

[10] Brewer MS. Irradiation effects on meat flavor: A review. Meat Science. 2009;81:1-14

[11] Mapiye C, Aldai N, Turner TD, Aalhus JL, Rolland DC, Kramer JKG, et al. Review—The labile lipid fraction of meat: From perceived disease and waste to health and opportunity. Meat Science. 2012;92:210-220

[12] Hwang Y-H, Joo S-T. Fatty acid profiles, meat quality, and sensory palatability of grain-fed and grass-fed beef from Hanwoo, American, and Australian crossbred cattle. Korean Journal for Food Science of Animal Resourches. 2017;37:153-161

[13] Gomide LAM, Ramos EM, Fontes PR. Ciência e Qualidade da Carne. 1st ed. Viçosa: UFV; 2013. 197p

[14] Wood JD, Enser M, Fisher AV, Nute GR, Sheard PR, Richardson RI, et al. Fat deposition, fatty acid composition and meat quality: A review. Meat Science. 2008;78:343-358

[15] Enser M, Hallett K, Hewitt B, Fursey GAJ, Wood JD. Fatty acid content and composition of English beef, lamb and pork at retail. Meat Science. 1996;42:443-456

[16] Ahmed ST, Islam M, Bostami ABMR, Mun H-S, Kim Y-J, Yang C-J. Meat composition, fatty acid profile and oxidative stability of meat from broilers supplemented with pomegranate (Punica granatum L.) by-products. Food Chemistry. 2015;188:481-488
[17] Oliveira EA, Sampaio AAM, Henrique W, Pivaro TM, Rosa BL, Fernandes ARM, et al. Quality traits and lipid composition of meat from Nellore young bulls fed with different oils either protected or unprotected from rumen degradation. Meat Science. 2012;90:28-35

[18] Scollan ND, Hocquette J-F, Nuernberg K, Dannenberger D, Richardson RI, Maloney A. Innovations in beef production systems that enhance the nutritional and health value of beef lipids and their relationship with meat quality. Meat Science. 2006;74:17-33

[19] Aharoni Y, Orlov A, Brosh A. Effects of high-forage content and oilseed supplementation of fattening diets on conjugated linoleic acid (CLA) and trans fatty acids profiles of beef lipid fractions. Animal Feed Science and Technology. 2004;117:43-60

[20] Schmid A, Collomb M, Sieber R, Bee G. Conjugated linoleic acid in meat and meat products: A review. Meat Science. 2006;73:29-41

[21] Alfaia CPM, Alves SP, Lopes AF, Fernandes MFE, Costa ASH, Fontes CMGA, et al. Effect of cooking methods on fatty acids, conjugated isomers of linoleic acid and nutritional quality of beef intramuscular fat. Meat Science. 2010;84:769-777

[22] Broncano JM, Petrón MJ, Parra V, Timón ML. Effect of different cooking methods on lipid oxidation and formation of free cholesterol oxidation products (COPs) in Latissimus dorsi muscle of Iberian pigs. Meat Science. 2009;83:431-437

[23] Brettonnet A, Hewavitarana A, Dejong S, Lanari MC. Phenolic acids composition and antioxidant activity of canola extracts in cooked beef, chicken and pork. Food Chemistry. 2010;121:927-933

[24] Lorenzo JM, Pateiro M. Influence of fat content on physicochemical and oxidative stability of foal liver pate. Meat Science. 2013;95:330-335

[25] Martino G, Haouet MN, Marchetti S, Grotta L. Effect of vitamin E supplementation on egg yolk quality and oxidative stability. Asian Journal of Agriculture and Food Sciences. 2014a;2:248-255

[26] Martino G, Mugnai C, Compagnone D, Grotta L, Del Carlo M, Sarti F. Comparison of performance, meat lipids and oxidative status of pigs from commercial breed and organic crossbreed. Animals. 2014b;4:348-360

[27] Martino G, Grotta L, Ponzielli V. Influence of dehydrated Medicago sativa on quality characteristics of Marchigiana beef. Animal Review. 2014c;1:37-44

[28] Min B, Ahn DU. Mechanism of lipid peroxidation in meat and meat products. Food Science and Biotechnology. 2005;14:152-163

[29] Fernández J, Pérez-àlvarez JA, Fernàndez-Lòpez JA. Thiobarbituric acid test for monitoring lipid oxidation in meat. Food Chemistry. 1997;59:345-353

[30] Gómez M, Lorenzo JM. Effect of fat level on physicochemical, volatile compounds and sensory characteristics of dry-ripened Bchorizo from Celta pig breed. Meat Science. 2013;95:658-666

[31] Papastergiadis A, Mubiru E, Van Langenhove H, De Meulenaer B. Malondialdehyde measurement in oxidized foods: Evaluation of the spectrophotometric thiobarbituric acid reactive substances (TBARs) test in various foods. Journal of Agricultural and Food Chemistry. 2012;60:9589-9594

[32] Grau A, Guardiola F, Boattella J, Barroeta A, Codony R. Measurement
of 2-thiobarbituric acid values in dark chicken meat through derivative spectrophotometry: Influence of various parameters. Journal of Agricultural and Food Chemistry. 2000;48:1155-1159

[33] Raharjo S, Sofos JN, Schmidt GR. Improved speed, specificity, and limit of determination of an aqueous acid extraction thiobarbituric acid-C18 method for measuring lipid peroxidation in beef. Journal of Agricultural and Food Chemistry. 1992;40:2182-2185

[34] Díaz P, Linares MB, Egea M, Auqui SM, Garrido MD. TBARs distillation method: Revision to minimize the interference from yellow pigments in meat products. Meat Science. 2014;98:569-573

[35] Jermann C, Koutchma T, Margas E, Leadley C, Ros-Polski V. Mapping trends in novel and emerging food processing technologies around the world. Innovative Food Science and Emerging. 2015;31:14-27

[36] Barba FJ, Grimi N, Vorobiev E. New approaches for the use of nonconventional cell disruption technologies to extract potential food additives and nutraceuticals from microalgae. Food Engineering Reviews. 2014;7:45-62

[37] Barbosa-Cánovas GV, Medina-Meza I, Candogan K, Bermúdez-Aguirre D. Advanced retorting, microwave assisted thermal sterilization (MATS), and pressure assisted thermal sterilization (PATS) to process meat products. Meat Science. 2014;98:420-434

[38] Ros-Polski V, Koutchma T, Xue J, Defelice C, Balamurugan S. Effects of high hydrostatic pressure processing parameters and NaCl concentration on the physical properties, texture and quality of white chicken meat. Innovative Food Science & Emerging Technologies. 2015;30:31-52

[39] Campus M, Flores M, Martinez A, Toldra F. Effect of high pressure treatment on colour, microbial and chemical characteristics of dry cured loin. Meat Science. 2008;80:1174-1181

[40] He Z, Huang Y, Li H, Qin G, Wang T, Yang J. Effect of high-pressure treatment on the fatty acid composition of intramuscular lipid in pork. Meat Science. 2012;90:170-175

[41] Ma HJ, Ledward DA, Zamri AI, Frazier RA, Zhou GH. Effects of high pressure/thermal treatment on lipid oxidation in beef and chicken muscle. Food Chemistry. 2007;104:1575-1579

[42] Mariutti L, Orlien V, Bragagnolo N, Skibsted L. Effect of sage and garlic on lipid oxidation in high-pressure processed chicken meat. European Food Research and Technology. 2008;227:337-344

[43] McArdle RA, Marcos B, Kerry JP, Mullen A. Monitoring the effects of high pressure processing and temperature on selected beef quality attributes. Meat Science. 2010;86:629-634

[44] Medina-Meza LG, Barnaba C, Barbosa-Canoas GV. Effects of high pressure processing on lipid oxidation: A review. Innovative Food Science & Emerging Technologies. 2014;22:1-10

[45] Orlien V. High-pressure-meat processing and milk gels. High Pressure Processing. 2009;12:56-58

[46] Rivas-Canedo A, Juez-Ojeda C, Nunez M, Fernandez-Garcia E, et al. Food Chemistry. 2011;124:749-758

[47] Andres A, Adamsen C, Møller J, Ruiz J, Skibsted L. High-pressure treatment of dry-cured iberian ham. Effect on colour and oxidative stability during chill storage packed in modified atmosphere. European Food Research and Technology. 2006;222:486-491
[48] Bolumar T, Skibsted LH, Orlien V. Kinetics of the formation of radicals in meat during high pressure processing. Food Chemistry. 2012;134:2114-2120

[49] Schindler S, Krings U, Berger RG, Orlien V. Aroma development in high pressure treated beef and chicken meat compared to raw and heat treated. Meat Science. 2010;86:317-323

[50] Byrnea DV, Brediea WLP, Mottram DS, Martens M. Sensory and chemical investigations on the effect of oven cooking on warmed-over flavour development in chicken meat. Meat Science. 2002;61:127-139

[51] Tornberg E. Effects of heat on meat proteins. Implications on structure and quality of meat products. Meat Science. 2005;70:493-508

[52] Das AK, Rajkumar V. Effect of different fat level on microwave cooking properties of goat meat patties. Journal of Food Science and Technology. 2011;50:1-6

[53] Chandrasekaran S, Ramanathan S, Basak T. Microwave food processing—A review. Foodservice Research International. 2013;52:243-261

[54] Serrano A, Librelotto J, Cofrades S, Sañchez-Muniz PJ, Jiménez-Colmenero F. Composition and physicochemical characteristics of restructured beef steaks containing walnuts as affected by cooking method. Meat Science. 2007;77:304-313

[55] Dominguez R, Gomez M, Fonseca S, Lorenzo JM. Effect of different cooking methods on lipid oxidation and formation of volatile compounds in foal meat. Meat Science. 2014;97:223-230

[56] Abida J, Rayees B, Masoodi FA. Pulsed light technology: A novel method for food preservation. International Food Research Journal. 2014;21:839-848

[57] Falguera V, Pagán J, Garza S, Garvín A, Ibarz A. Ultraviolet processing of liquid food: A review. Part 1: Fundamental engineering aspects. Food Research International. 2011;44:1571-1579

[58] Guerrero-Beltrán JA, Barbosa-Cánovas GV. Advantages and limitations on processing foods by UV light. Food Science and Technology International. 2004;10:137-147

[59] Kim T, Silva JL, Chen TC. Effects of UV irradiation on selected pathogens in peptone water and on stainless steel and chicken meat. Journal of Food Protection. 2002;65:1142-1145

[60] Lyon SA, Fletcher DL, Berrang ME. Germicidal ultraviolet light to lower numbers of Listeria monocytogenes on broiler breast fillets. Poultry Science. 2007;86:964-967

[61] Koutchma T, Forney L, Moraru C. Principles and applications of UV technology. In: Koutchma T, Forney L, Moraru C, editors. Ultraviolet Light in Food Technology. Boca Raton, FL: CRC Press; 2009. pp. 1-32

[62] Raghavan GSV, Rennie TJ, Sunjka PS, Orsat V, Phaphuangwittayakul W, Terdtoon P. Overview of new techniques for drying biological materials with emphasis on energy aspects. Brazilian Journal of Chemical Engineering. 2005;22:195-201

[63] Freitas JA. Introdução à hygiene e conservação das matérias-primas de origem animal. 1st ed. São Paulo: Atheneu; 2015. p. 422

[64] Turp GY, Icier F, Kor G. Influence of infrared final cooking on color, texture and cooking characteristics of ohmically pre-cooked meatball. Meat Science. 2016;114:46-53

[65] Alam Khan K, Abrahem M. Effect of irradiation on quality of spices.
Lipid Peroxidation

International Food Research Journal. 2010;17:825-836

[66] Otto C, Zahn S, Rost F, Zahn P, Jaros D, Rohm H. Physical methods for cleaning and disinfection of surfaces. Food Engineering Reviews. 2011;3:171-188

[67] Ahn DU, Lee EJ. Mechanisms and prevention of off-odor production and color changes in irradiated meat. In: Komolprasert V, Morehouse KM, editors. Irradiation of Food and Packaging: Recent Developments. Washington, DC: ACS Symposium Series; 2004. pp. 43-76

[68] Jo C, Ahn DU. Volatiles and oxidative changes in irradiated pork sausage with different fatty acid composition and tocopherol content. Journal of Food Science. 2000;65:270-275

[69] Zhu MJ, Mendonca A, Lee EJ, Ahn DU. Influence of irradiation and storage on the quality of ready-to-eat Turkey breast rolls. Poultry Science. 2004;83:1462-1466

[70] Kim IS, Jo C, Lee KH, Lee EJ, Ahn DU, Kang SN. Effects of low-level gamma irradiation on the characteristics of fermented pork sausage during storage. Radiation Physics and Chemistry. 2012;81:466-472

[71] Kang S, Park SY, Ha SD. Application of gamma irradiation for the reduction of norovirus in traditional Korean half-dried seafood products during storage. LWT- Food Science and Technology. 2016;65:739-745

[72] Contini C, Alvarez R, O'Sullivan M, Dowling DP, Gargan SO, Monahan FJ. Effect of an active packaging with citrus extract on lipid oxidation and sensory quality of cooked Turkey meat. Meat Science. 2014;96:1171-1176

[73] Pindi W, Mah HW, Munsu E, Ab Wahab N. Effects of addition of Kappaphycus alvarezii on physicochemical properties and lipid oxidation of mechanically deboned chicken meat (MDCM) sausages. British Food Journal. 2017;119:2229-2239

[74] Panda AK, Cherian G. Tissue tocopherol status, meat lipid stability, and serum lipids in broiler chickens fed Artemisia annua. European Journal of Lipid Science and Technology. 2017;119:1-7

[75] Bolumar T, Andersen ML, Orlier V. Antioxidant active packaging for chicken meat processed by high pressure treatment. Food Chemistry. 2011;129:1406-1412

[76] Badr HM, Mahmoud KA. Antioxidant activity of carrot juice in gamma irradiated beef sausage during refrigerated and frozen storage. Food Chemistry. 2011;127:1119-1130