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Review

Prediction of meat and meat products by gamma rays, electron beams and X-ray irradiations-A Review

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Food quality is directly related to people's health and social progress. Consumers are looking for quality seals and trust marks on food products, and expect manufacturers and retailers to provide products of high quality. In practice, it is more necessary to develop fast and efficient spectroscopic tools as useful technology to accomplish meat and meat products quality detection. Irradiation, results in physicochemical changes in food products. Ionizing radiation includes gamma rays, electron beams, and X-rays. Ionizing radiation is effective at eliminating food pathogens in poultry and other foods. Some physico-chemical, microbiological and sensory properties of fermented sausages have been realized by E-beam radiation. Gamma irradiation in combination with antioxidant addition (tea poly-phenol) was used in the pork industry to assure quality product with prolonged shelf-life. X-ray irradiations e.g. computed and micro-computed tomography was used successfully for prediction assessment and estimation of salt and water content in dry-cured ham, sodium chloride diffusivity of fresh and frozen/thawed ham muscles during salting and intramuscular fat level and distribution in beef muscles. This review article presents the most recent trends, during the last four years, concerning the ability of Gamma Rays, Electron beams and X-ray radiations for quality predictions of meat and meat products.

Key words: Irradiation, gamma rays, electron beams, X-ray, meat and meat products, prediction.

INTRODUCTION

The irradiation technology implies the exposure of meat products to ionizing irradiation to decontaminate food products. This irradiation can (i) increase food safety and reduce food borne illness; (ii) lengthen the shelf-life of many perishable products; and (iii) reduce the risks of post-processing contamination of intact, packaged products. Ionizing irradiation occurs when one or more electrons are removed from the electronic orbital of the atom. It can be produced by three different techniques (Gamma rays, E-beam and X-rays)

Gamma ray is mainly produced by a source of radio-nuclides, Cobalt ^{60} with a half life of 5.27 years and Cesium ^{137} with a half life of 30.19 years. In the industry, the majority of facilities use the Cobalt^{60} because it has stronger gamma ray and it is not soluble in water Ahn and Lee (2006). Electron beams (also called β-irradiation) are produced by commercial electron accelerators and therefore can be switched off like all electrical apparatus. They can be directly used for small items such as grains or to remove surface contamination because they have limited penetration capacity.

X-rays are produced when fast moving electrons slam into a metal object. If the target used is tantalum or platinum, strong X-ray with an energy superior to 1 MeV can be produced. US Food and Drug Administration (USFDA) and the European Commission approved the use of X-ray technology with a maximum energy of 5 MeV, and then the FDA amended the maximum level to reach 7.5 MeV at 2004. The technique offers the possibility of processing packaged meat products in great quantities (Borsa, 2006) although it requires a high investment and maintenance cost. Food irradiation facilities must be designed and constructed in order to ensure the control of the radiological hazard for the personal and the environment.

Moreover, the energy of gamma-rays and X-rays can be transferred to other atomic particles. Gamma-rays do not ionize atoms directly but transfer energy to other atomic particles which interact with other materials to form ions. Gamma-rays can pass through living tissues without interacting with them because they are so high energy and

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so small. Gamma-rays are emitted from the nucleus of radioactive atoms; X-rays are emitted from the electron field (Efiok, 1996). Radio-nuclides approved for food irradiation, ^{137}Cs and ^{60}Co, produce Gamma-rays as they decay over time. They have short half lives (^{137}Cs = 30 yr; ^{60}Co = 5.2 y) compared to radioisotopes (^{234}Ur = 25,000 yr).

Irradiation dose is measured in Grays, the amount of energy per unit mass. The amount of energy to which a food is exposed is expressed as the ‘‘radiation absorbed dose” (rad). 1 kGy raises the food temperature by <0.5° F.

1 Gray = 1 joule of energy absorbed/kg food, 1 Gray = 6200 billion MeV absorbed/kg food, 1 Gray = 100 Rads (or 0.022 calorie/kg of food), 1 Rad = 100 erg/g (Brewer, 2009) also see (Farkas and Mohacsi-Farkas, 2011).

Irradiation has recently become one of the successful techniques to preserve food with minimum interruption to the functional, nutritional, and sensory properties of food products. This processing of food involves controlled application of energy from ionizing radiations such as gamma rays, X-rays, and electron beam for food preservation. Irradiation preserves the food by disrupting the biological processes that lead to decay of food quality. Radiations also damage DNA molecules effectively, so living cells such as in microorganisms, insects, and gametes are prevented from reproduction, resulting in a preservative effect. Irradiation, like other processing techniques, results in physicochemical changes in food products.

Therefore, this review summarizes the recent four-year published articles concerning application of ionizing irradiations (Gamma rays, Electron beams and X-ray) to predictions of the chemical composition, safety and quality of meat and meat product's.

Gamma Irradiations

Effects of gamma-irradiation before and after cooking on bacterial population and sensory quality of Dakgalbi

Dakgalbi has been recognized as a health-food as it consists of low-fat, low-calorie, low-cholesterol and high-protein chicken meat as well as plenty of vegetables, become a national favorite on the basis of consumer preference. Dakgalbi, despite of its very short shelf-life, is even being developed as a space food for Korean astronauts and as a special purpose food for patients

Two types of Dakgalbi were prepared: Dakgalbi cooked with gamma-irradiated chicken meat and sauce (IBC), raw chicken meat and Dakgalbi sauce were irradiated and then stir-fried. For the preparation of Dakgalbi irradiated after cooking with fresh raw chicken meat and sauce (IAC), raw chicken meat and Dakgalbi sauce were first cooked and subsequently irradiated.

Under the accelerated storage condition of 35 °C for 7 days, bacteria in (IBC) were below the detection limit (1log CFU/g) on day 1 but were detected on day 2 and gradually increased thereafter. In (IAC), on the other hand, bacteria were not detected at all. Evaluation of sensory quality also decreased in both samples. However, (IAC) showed a better trend. The results indicated that (IAC) protocol was a more effective method for reducing bacterial growth in Dakgalbi. So, the results indicated that gamma irradiation can improve the bacterial hygiene of Dakgalbi. The results also showed that (IAC) Dakgalbi has a much longer shelf-life and a better trend with respect to sensory quality than (IBC) Dakgalbi, indicating that the sequential position of gamma irradiation in Dakgalbi preparation is important (MinYoon et al., 2012).

Effects of low-level gamma irradiation on the characteristics of fermented pork sausage during storage

Dry fermented sausages being relatively high fat foodstuffs and long period of manufacturing steps and post-fermentation storage, lipid oxidation can damage their sensorial properties, which are associated to rancid taste and odor. The quality characteristics of irradiated fermented sausages would be very important for the acceptance of irradiation technology. Several methods, which include cooking, freezing, fermenting, salting, drying, and pickling (Kim et al., 2006) have been used to reduce the number of microorganisms and increase the shelf-life and safety of meat.

The effect of low-level gamma-irradiation (0.5, 1, 2 and 4 kGy) on the color, lipid oxidation, microbial counts, and sensory characteristics of vacuum-packaged dry fermented sausages during storage was studied. Gamma irradiation (0.5, 1, 2, and 4kGy) effect on the quality of vacuum-packaged dry fermented sausages during refrigerated storage was evaluated. On Day 0 of irradiation, the pH, redness (CIE a^*), yellowness (CIE b^*), 2-thiobarbituric acid-reactive substances (TBARS) and volatile basic nitrogen (VBN) values of samples irradiated at 2 and 4kGy were higher ($p < 0.05$), but the CIE L^* values (lightness) were lower than those of the non-irradiated control ($p < 0.05$). At <1 kGy irradiation, however, the pH, CIE L^*, CIE a^* and CIE b*-value of samples were not significantly influenced by irradiation.

The CIE a*, and CIE b*-values of samples irradiated at 2 and 4kGy decreased with the increase of storage time. The VBN, TBARS, and CIE Ln-values of samples irradiated at 4kGy were not changed significantly during refrigerated storage for 90 days (p< 05). The total plate counts (TPC) and lactic acid bacteria (LAB) in the samples irradiated at 4k Gy were significantly lower ($p < 0.01$) than those with lower irradiation doses.

At the end of storage, the TPC, coliform, and LAB in the

samples were not increased after irradiation at 0.5, 1 and 2kGy, respectively. TPC and LAB were not detected in samples irradiated at 4 kGy at Day 90. In addition, no coliform bacteria were found in samples irradiated at1kGy during refrigerated storage. Sensory evaluation indicated that the rancid flavor of samples irradiated at 4kGy was significantly higher, but aroma and tastes cores were lower than those of the controls at Day 3 of storage.
Irradiation of dry fermented sausages at 2kGy was the best conditions to prolong the shelf-life and decrease the rancid flavor without significant quality deterioration (Kim et. al., 2012).

Toxicological Evaluation of Chicken-Breast Meat with High-Dose Irradiation

A complete toxicological assessment of irradiated chicken-breast meat with high doses, including test of genotoxicity, acute oral toxicity, and a 30-d sub-chronic toxicity was conducted in order to evaluate the safety of ^{60}Co-irradiated chicken breast meat as a pet food.
Toxicity and safety of high-dose irradiated chicken-breast meat were evaluated. For assays of acute toxicity, genetic toxicity, and sub-chronic toxicity, ames test, mice bone marrow erythrocyte micronucleus, and mice sperm abnormality were performed. The results showed that, in the acute oral toxicity tests, median lethal dose (more than 10000 mg kg^{-1}) in male and female ICR mice rats showed no toxicological signs. For sub-acute 30-d oral toxicology of irradiated chicken-breast meat with dose of 10, 15 and 25 kGy in both male and female SD rats, no noticeable toxicological effects were observed. It is concluded that chicken-breast meat with high-dose irradiation has no acute toxicity and no genotoxicity, nor harmful effects on the animal body at the tested dosage range. Therefore, high-dose irradiated chicken-breast meat is safe for pet consumption (Jia-ting et. al., 2012).

Effect of the Gamma Radiation Dose Rate on Psychrotrophic Bacteria, Thiobarbituric Acid Reactive Substances, and Sensory Characteristics of Mechanically Deboned Chicken Meat

This study has been aimed to verify the effects of different gamma radiation doses rates on the sensory characteristics, psychrotrophic bacteria, and thiobarbituric acid reactive substances (TBARS) of Mechanically Deboned Chicken Meat MDCM during refrigerated storage.
Frozen samples of (MDCM) with skin were irradiated with gamma radiation doses of 0.0 kGy (control) and 3 kGy at 2 different radiation dose rates: 0.32 kGy/h (3 kGy) and 4.04 kGy/h (3 kGy). Batches of irradiated and control samples were evaluated during 11 days of refrigerated (2±1°C) storage for the following parameters: total psychrotrophic bacteria count, (TBARS), evaluation of objective color ($L*$, $a*$, and $b*$) and a sensory evaluation (irradiated odor, oxidized odor, pink and brown colors). No statistical difference ($P > 0.05$) was found amongst the TBARS values obtained for the MDCM samples irradiated with dose rates of 0.32 and 4.04 kGy/h.
There was a significant increase ($P < 0.05$) in the psychrotrophic bacterial count as from the 7th day of refrigerated storage, for the MDCM samples irradiated at the dose rate of 4.04kGy/h. With respect to the attribute of oxidized odor, the samples irradiated with a dose rate of 0.32 kGy/h showed a stronger intensity and were significantly different ($P < 0.05$) from the sample irradiated with a dose rate of 4.04 kGy/h on days 0 and 2 of refrigerated storage. Irradiation with a dose rate of 4.04 kGy/h (3kGy) was shown to be the best condition for the processing of MDCM according to the evaluation of all the variables, under the conditions of this study.
Accordingly, the results revealed that the dose rates studied, that of 4.04 kGy/h was considered the best for the processing of the MDCM sample. Both the irradiated samples had a shelf life of 4 to 7 d, quite superior to the control sample, which had a shelf life of 0 to 2 days under the conditions of the study (Brito et al., 2011).

Effect of irradiation and storage time on lipid oxidation of chilled pork

The objective of this study was to determine the effect of gamma irradiation at (0, 2, 4, 6, 8 and10 kGy) doses and storage time (0–30 days) on lipid oxidation of chilled pork.
This irradiation at doses were found to induce changes in lipid oxidation of chilled pork immediately after irradiation, and affected the peroxide value (PV) and thiobarbituric acid reactive substance (TBARS) values during refrigerated storage. However, gamma irradiation could retard microbial growth in pork, leading to the retardation of spoilage and putridity. Shelf-life of marble meat from landrace pig could be extended by irradiation at 2-10 kGy in combination with the refrigerated storage. In addition, antioxidant tea polyphenol (TP) can decrease the lipid oxidation of chilled pork after irradiation, prolong the shelf-life and improve the safety of chilled pork. Therefore, irradiation in combination with antioxidant addition may be used in the pork industry to produce a prime quality product with prolonged shelf-life (Cheng et al., 2011).

Effect of gamma-ray irradiation on the fatty acid profile of irradiated Beef meat

This study used NMR spectroscopy in conjunction with gas chromatography (GC) to assess the effect of irradiation doses on the fatty acid profile in the triacylglycerols composition of beef meat. It was demonstrated that the fatty acid contents can be measured with ^{1}H NMR spectroscopy as accurately as with GC. In addition, a dose-dependent effect of irradiation on the fatty acids components of the triacylglycerol composition was revealed and confirmed by these techniques.

Gamma-ray irradiation on the fatty acid profile of beef meat was examined at doses of 2.5, 5.0, 7.5, 10.0 and 15.0 kGy by means of ^{1}H NMR spectroscopy. NMR results revealed a clear trend toward an increase in the amount of saturated fatty acids and a decrease in the amount of polyunsaturated fatty acid in the triacylglycerol composition of the irradiated samples compared to the un-irradiated sample with increasing the irradiation dose. The observed changes in the fatty acid profile were confirmed by gas chromatography analysis of the samples irradiated at doses of 7.5, 10.0 and 15.0 kGy. Additionally, the linear correlation of the observed changes in the total saturated fatty acid (TSFA) amount with the applied irradiation dose facilitates its assignment; therefore, a previously obtained TSFA from the NMR analysis allows one to predict or to approximate the absorbed dose (Stefanova et al., 2011).

Maintenance of Safety and Quality of Refrigerated Ready-to-Cook Seasoned Ground Beef Product (Meatball) by Combining Gamma Irradiation with Modified Atmosphere Packaging

The effects of gamma irradiation combined with modified atmosphere packaging on *Escherichia coli* O157:H7, *Salmonella enteritidis*, *Listeria monocytogenes,* lipid oxidation, color changes, and sensory qualities of ready-to-cook Meat balls during refrigerated storage were studied.

Meatballs were prepared by mixing ground beef and spices and inoculated with *E. coli* O157:H7, *L. monocytogenes*, and *S. enteritidis* before packaged in modified atmosphere (3% O_2 + 50% CO_2 + 47% N_2) or aerobic conditions. The packaged samples were irradiated at 0.75, 1.5, and 3 kGy doses and stored at 4 °C for 21 d. Survival of the pathogens; total plate count, lipid oxidation, color change, and sensory quality were analyzed during storage. Irradiation at 3 kGy inactivated all the inoculated (approximately 10^6 CFU/g) *S. enteritidis* and *L. monocytogenes* cells in the samples. The inoculated (approximately 10^6 CFU/g) *E. coli* O157:H7 cells were totally inactivated by 1.5 kGy irradiation. D^{10}-values for *E. coli* O157:H7, *S. enteritidis*, and *L. monocytogenes* were 0.24, 0.43, and 0.41 kGy in modified atmosphere packaging (MAP) and 0.22, 0.39, and 0.39 kGy in aerobic packages, respectively.

Irradiation at 1.5 and 3 kGy resulted in 0.13 and 0.36 mg MDA/kg increase in 2-thiobarbituric acid-reactive substances (TBARS) reaching 1.02 and 1.49 malondialdehyde/kg(MDA/kg) respectively on day 1. Irradiation also caused significant loss of color and sensory quality in aerobic packages. However, MAP effectively inhibited the irradiation-induced quality degradations during 21-d storage. Thus, combining irradiation (3 kGy) and modified atmosphere packaging (MAP: 3% O_2 + 50% CO_2 + 47% N_2) controlled the safety risk due to the potential pathogens and maintained qualities of meatballs during 21-d refrigerated storage (Gunes et al, 2011).

Detection of the Indigenous salmonella level in a radiation-sterilized pure culture and meat model system

Evaluation of quantitative detection of the radiation-sterilized *S. typhimurium* in a pure culture and ground beef, pork and chicken meat model system using a visual immune-precipitate (VIP) assay kit and an enzyme-linked immune-sorbent assay (ELISA) method was carried out. The VIP kit and ELISA detected 105 cells /mL or above of the enriched culture of *S. typhimurium*, and the detection limit of the irradiated Salmonella was comparable to that of the intact cells. There was no significant difference between the detection limit of the enriched culture and that of inoculated and irradiated *S. typhimurium* in model system of ground beef, pork and chicken.

Irradiation did not give any effect on the immunochemical detection of *S. typhimurium* within a dose of 5 kGy; therefore, an immune detection method may be a simple way for the quantitative analysis of the indigenous microbes in a radiation-sterilized food as well this simple test will be helpful by giving a result for consumer and manufacturer to verify that their products are produced under hygienic standard before irradiation treatment (Kim et al., 2010).

Effect of Gamma Radiation on Frozen Turkey Breast Meat Quality

This work has been conducted to evaluate the irradiation process influence on the turkey meat preservation using two different dose rates. Results were expressed as a commercial shelf life of the turkey meat cuts (frozen, frozen and irradiated at 1 kGy dose, and frozen and irradiated at 3 kGy dose). The following analytical procedures were used: bacteriological (psychrophiles and *Enterococcus* spp.), sensory (acceptance test), chemical (thiobarbituric acid reactive substances and peroxide value (PV) and physical (pH and colorimetry) in order to indicate the use of irradiation and confirm the irradiation and the dose values absorbed in the samples by electron paramagnetic resonance spectroscopy.

Nine male turkey breasts with bone were frozen at -18 °C, cut, vacuum packed and irradiated with gamma rays (1 kGy and 3 kGy doses) and stored for 540 days at -18 °C. During that time, bacteriological, physical and chemical analyses as well as a sensory evaluation were conducted after 5, 180, 360 and 540 days of storage. The psychrophiles counts and the counts of *Enterococcus spp*. increased during the storage period; moreover, the count was lower because of the irradiation by gamma rays, especially at a dose rate of 3 kGy.

The lipid oxidation increased according to the irradiation dose used and the storage time. In the beginning of the storage, the gamma radiation helped to reduce the sensory acceptance of the meat taste, especially when the sample was subjected to a dose of 3 kGy, which was then confirmed as the one with the greatest lipid oxidation. Therefore, Gamma radiation was efficient in making the psychrophiles inactive, in a proportional way to an increase in the dose from 1 kGy to 3 kGy and in the destruction of *Enterococcus* bacteria as there were fewer recovered when the turkey breast samples were irradiated at doses of 3 kGy.

The irradiation process accelerated the lipid oxidation proportionally to the doses used and to the storage periods studied; however, it was not considered unacceptable for a period of up to 540 days. Irradiated meat samples were within the pH range that characterizes the meat as fit for consumption until the maximum storage time and did not show any change in the sensory characteristics of flavor, color and overall impression (Henry et al., 2010).

Enhancement of microbial quality and inactivation of pathogenic bacteria by gamma irradiation of ready-to-cook Iranian barbecued chicken

The effect of gamma irradiation (0, 1.5, 3 and4.5kGy) on the microbial quality of ready-to-cook (RTC) barbecued chicken samples stored at 4 °C for 15days was investigated. Effectiveness of irradiation for inactivating *Listeria monocytogenes*, *Escherichia coli* O157:H7and *Salmonella typhimurium* inoculated into the samples was also studied.

Irradiation of the samples resulted in a dose dependent reduction in counts of aerobic mesophilic bacteria, yeasts and molds, *Enterobacteriaceae* and lactic acid bacteria. Among the microbial flora, yeasts and molds and *Entero bacteriaceae* were more sensitive to irradiation and got completely eliminated at dose of 3kGy. D_{10} values of *L. monocytogenes*, *E. coli* O157:H7and *S. typhimurium* inoculated into the samples were 0.680, 0.397 and 0.601kGy, respectively.

An irradiation dose of 3kGy reduced the counts of *E. coli* O157:H7 to an undetectable level in RTC barbecued chicken but was ineffective on elimination of *L. monocytogenes* and *S. typhimurium*. However, none of the food-borne pathogens were detected in the samples irradiated at 4.5kGy. At the end of the storage period, irradiated samples were more acceptable compared to non-irradiated ones. Therefore, irradiation significantly improved the microbiological quality of aerobically packaged RTC Iranian barbecued chicken by reducing the microbial flora without undesirable and detrimental effects on the sensory acceptability (Fallah et al., 2010a).

Chemical Quality, Sensory Attributes and Ultra structural Changes of Gamma Irradiated Camel meat

Camel meat is healthier as it contains less intramuscular fat and cholesterol as well as being relatively richer in polyunsaturated fatty acids (PUFAs) than beef (Kadim et al*.* 2006).

This research article investigated the chemical quality, sensory attributes and ultra-structural changes of gamma irradiated camel meat during the 15 days of refrigerated storage at 4±1°C. Thus, aerobically packaged fresh camel meat samples (*Biceps femoris muscles*) were subjected to gamma irradiation at doses of 0 (control), 1.5 and 3.0 kGy and stored at 4±1°C for 15 days.

The results showed that Irradiation had no significant effects ($P > 0.05$) on proximate composition, total volatile nitrogen (TVN) and cooking loss but significantly ($P < 0.05$) increased lipid oxidation in terms of thiobarbituric acid reactive substances (TBARS). Also, refrigerated storage significantly ($P < 0.05$) increased TVN, cooking loss and TBARS of non-irradiated and irradiated samples.

This study showed that irradiation had no significant effects ($P > 0.05$) on the sensory attributes of raw and cooked camel meat. The irradiated samples were more acceptable during storage. At ultra-structural observation, transmission electron micrographs showed structural changes of myofibrils in irradiated samples when compared with non-irradiated ones. Moreover, the mean size of sarcomere length of irradiated samples was significantly ($P < 0.05$) shorter than that of non-irradiated camel meat (Fallah et al., 2010).

Effects of gamma irradiation and electron beam irradiation on quality, sensory, and bacterial populations in beef sausage patties

The effects of gamma ray (GR) and electron beam (EB) irradiation were compared on quality (TBARS value, hardness, color), sensory characteristics, and total bacterial populations in beef sausage patties during accelerated storage at 30°C for 10 days. Beef sausage patties were vacuum-packaged and irradiated by GR and EB at 0, 5, 10, 15, and 20 kGy at room temperature.

The results of quality evaluation showed that the effects of GR irradiation were similar ($p \geq 0.05$) to electron beam (EB) irradiation on lipid oxidation, hardness, color and sensory scores of the beef sausage patties. However, GR-irradiated samples had lower ($p<0.05$) total bacterial counts than EB-irradiated samples after irradiation, and during storage regardless of irradiation dose.

The results indicated that use of GR irradiation up to 10 kGy on patties should be useful in reducing bacterial populations with no adverse effect on quality and most of sensory characteristics (color, chewiness, and taste). Therefore, GR irradiation may be more effective in decreasing bacterial populations compared to EB irradiation, and both of GR and EB irradiation did not have adverse effects on lipid oxidation and most sensory characteristics (color, chewiness, and taste) up to 5 kGy and 10 kGy, respectively (Park et al., 2010).

Effects of γ-irradiation upon biogenic amine formation in Egyptian ripened sausages during storage

From a toxicological point of view, consumption of excessive amounts of biogenic amines (Bas) can pose a health risk, especially in unhealthy or immuno-compromised individuals. γ-irradiation can be effective in reducing the major BAs in ground beef and pork (Min et al., 2007), following inoculation with three different microorganisms.

Therefore, the effects of γ-irradiation upon the biogenic amine inventory in Egyptian fermented sausages were investigated during storage for up to 30 days.

Typical contents of biogenic amines in non-irradiated sausages ranged between 277 and 5815 mg/kg_{DW}; irradiation with 2, 4 and 6 kGy decreased the total contents to 186-111, 188-98 and 180-57 mg/kg_{DW} by the end of storage, respectively. Cadaverine was the major amine in non-irradiated samples-where it accounted for 44% of the total by 30 days; however, tyramine dominated in irradiated samples, where it accounted for 50%. On the other hand, the histamine content in non-irradiated sausage by 30 days of storage (i.e. 768 mg/kg_{DW}) clearly exceeded the maximum allowable of 100 mg/kg, unlike happened in their irradiated counterparts. Therefore, the dramatic reduction observed in the histamine levels suggests that the use of this preservation technique will be beneficial for such a traditional processed meat. In general, histamine can be hazardous in non-irradiated Egyptian fermented sausages, after storage for a 30 day-period, because of the high value attained thereby (768 mg/kg_{DW}). In irradiated samples, histamine was detected immediately after irradiation, but not afterwards; and a decreasing tendency in the levels of all BAs was observed at storage time elapsed - a trend that was especially significant following 6 kGy-irradiation. So, it has been concluded that γ–irradiation appeared to be effective in preventing formation of BAs, thus allowing the shelf life of fermented sausages to be significantly extended (Rabie *et al*. 2010).

Influence of gamma irradiation and storage on the microbial load, chemical and sensory quality of chicken kabab

Chicken kabab was treated with 0, 2, 4 or 6kGy doses of gamma irradiation. Treated and untreated samples were kept in a refrigerator (1-4 °C). Microbiological, chemical and sensory characteristics of chicken kabab were evaluated at 0–5months of storage. Gamma irradiation decreased the microbial load and increased the shelf-life of chicken kabab. Irradiation did not influence the major constituents of chicken kabab (moisture, protein and fats).

No significant differences ($p>0.05$) were observed for total acidity between non-irradiated (control) and irradiated chicken kabab. Thiobarbituric acid (TBA) values (expressed as mg malonaldehyde (MDA)/kg chicken kabab) and volatile basic nitrogen (VBN) in chicken kabab were not affected by the irradiation. Sensory evaluation showed no significant differences between irradiated and non-irradiated samples. Thus, the doses of 4 and 6 kGy were necessary for reducing all microorganisms in chicken kabab to undetectable levels and for extending its shelf-life. Furthermore, the nutritional macro-components and sensorial characteristics (taste, flavor, color, and texture) of the chicken kabab product were not influenced by the irradiation treatment. (Al-Bachir et al., 2010).

Electron Beam Irradiation

Effects of the storage time on the folic acid added to ready-to-eat meat products manufactured by irradiation

Folic acid (FA) is considered as one of the most important bioactive compounds in the human diet (Food and Drug Administration, 1996); World Health Organization (WHO, 2006).

This research work examined the effect of storage time on Folic acid (FA) stability and on the sensory properties of these irradiated meat products. For that, a theoretical model has been used in which the meat products were enriched with 2.4 mg FA/100 g of the final product. This amount is higher than the Daily Tolerable Upper Intake Level proposed by the European authorities (Scientific Advisory Committee on Nutrition (SACN) (2006). However, it has been selected in order to compensate the possible losses of FA during the storage and to assure a sufficient amount giving the 100% of the RDA per serving of the final product.

Three different meat products enriched with folic acid (FA) (2.4mg/100g) were prepared as ready-to-eat (RTE) products using E-beam radiation (2 and 3kGy) to ensure their safety. The stability of FA and sensory properties of the irradiated meat products were studied during three months of storage under freezing conditions for hamburgers and refrigeration conditions for cooked and dry fermented sausages. FA content was stable in non-irradiated and irradiated hamburgers and cooked sausages over the storage period, whereas it decreased 20% in non-irradiated dry fermented sausages and 12–8% of irradiated

samples at 2 and 3kGy, respectively.
Nevertheless, the final amount remained sufficient to provide the recommended daily intake. Panelists rated the sensory properties of the hamburger as satisfactory even after irradiation and 90 days of storage. The over-all acceptability of RTE cooked and dry fermented sausages improved slightly with storage (P >0.05) (Galan et al., 2012a).

Effect of electron-beam irradiation on cholesterol oxide formation in different ready-to-eat foods

Cholesterol oxidation products (COPs) have received considerable attention in recent years because of their biological activities associated with human diseases, such as the inhibition of cholesterol biosynthesis, atherosclerosis, changes in membrane properties, cytotoxicity, mutagenesis and carcinogenesis (Bösinger *et al*., 1993; Yin et al., 2000; Poli, Sottero, Gargiulo, & Leonarduzzi, 2009).
E-beam irradiation generates ions and free radicals which may cause the oxidation of different compounds; unsaturated fatty acids are the most affected, producing lipid oxidation which gives rise to COPs. The susceptibility of cholesterol to oxidation is well known and more than seven oxidation products (Smith, 1981) have been described. Those most frequently observed in food are the following: 7-ketocholesterol, 7α- and 7β-hydroxycholesterol, 5,6α- and 5,6-β-epoxide, cholestanetriol and 25- hydroxycholesterol.
The object of this study was to research the effect of E-beam irradiation on COP formation in several food samples of animal origin (cooked ham, Spanish Serrano ham, minced beef and soft cheese). Non-irradiated and irradiated food samples were analyzed and results were compared by ANOVA. Correlations between lipids and produced COPs were established.
The formation of cholesterol oxidation products (COPs) was carried out in four ready-to-eat (RTE). The samples were previously treated with electron-beam irradiation between 1 and 8 kGy. Three COPs, 25-hydroxycholesterol, 7-ketocholesterol and 6-ketocholestanol, were extracted together with the lipid fraction using chloroform.
Then, COPs were isolated by sample clean up using solid phase extraction (SPE) and were analyzed by high performance liquid chromatography with ultraviolet detection (HPLC-UV). Method validation was established with precision and recovery studies. Results showed that non-irradiated cheese and cooked ham samples did not contain COPs. In general, an increase in COP content was observed in all cases when the irradiation dose increased, although this increase was not linear. The 6-keto COP was not detected in any of the RTE food samples studied regardless of the irradiation dose. The results cleared also that an increase in the 25-OH and 7-keto COP content has been detected after E-beam irradiation with doses from 1 to 8 kGy, which is in the upper accepted limit in other foods, but final COP concentrations found in the foodstuffs studied here were at least one order of magnitude lower than those which produce toxic effects in *in vivo* and *in vitro* experiments. Analysis was made by HPLC with UV detection; so, two COPs with absorption properties were used as targets (Lozada-Castro et al, 2011).

Irradiation is useful for manufacturing ready-to-eat cooked meat products enriched with folic acid

Folic acid (FA) is the term most commonly used to refer to a family of vitamins found widely in foodstuffs. Fresh and dry-fermented meat products enriched with FA have been developed and prepared as RTE using E-beam irradiation (Galán et al., 2010b). The aim of this study was to manufacture cooked sausages enriched with FA and to prepare them as RTE products. The irradiated products were analyzed for loss of FA, in order to detect decreases in the functional effects of the food. In addition, the physico-chemical and sensory properties of the final product were measured.
Cooked sausages enriched with FA (0.6, 1.2 and 2.4 mg/100 g) were manufactured as ready-to-eat (RTE) products using E-beam radiation (2–4 kGy) as a non-thermal technology. The effects on the FA content, color, texture and sensory properties of the final products were studied.
The characteristics of sausages were not affected by the presence of FA, independently of the amount added, and their overall acceptability was good. Physico-chemical and sensory properties of the sausages were accepted up to doses of 3 kGy. Doses of 4 kGy caused losses of FA close to 20–30% and significantly decreased the sensory quality ($P < 0.05$). Despite this, the final content of FA in all products was sufficient so that 50 g of product gave 100% of the recommended daily allowance (RDA) (Galán et al., 2011c).

Effects of ionizing irradiation on the quality and sensory attributes of ready-to-eat dry fermented sausages enriched with folic acid

Previous works performed in cooked sausages (Cáceres et al. 2008) indicated that the incorporation of folic acid into meat products could also be a good way to provide consumers with this important nutrient, thereby improving the nutritional quality of meat products. Despite the potential nutritional value of meat products fortified with FA, their production has not been studied extensively (Galan *et al*., 2010b). Dry fermented sausage enriched with FA as a new candidate functional meat product was manufactured to determine its effects on the quality and sensory properties of these sausages. The effect of E-beam irradiation on the FA content, texture, color parameters and sensory properties when enriched sausages are prepared as RTE products was studied.

Dry fermented sausages have been manufactured with different concentrations of FA (0.6, 1.2 and 2.4 mg per 100 g of original mixture). Then, they were prepared as ready-to-eat meat products by using E-beam radiation (2, 3 and 4 kGy) to increase their safety. The stability of this vitamin as well as the physicochemical properties, microbiological counts, color, texture and sensory properties of the sausages was studied after irradiation.

The most important changes were observed in hardness, which increased with increasing FA amount; in contrast, color was similar in all batches, independently of FA concentration or irradiation doses applied. The sensory properties of these products were judged acceptable to tasters, although significant differences were observed between the taste of non-irradiated and irradiated samples with 3 kGy. The ionizing treatment caused a decrease of 15-29% in the FA content only at the highest dose (4 kGy). Despite this loss, this new product is suitable for assuring the daily intake of FA recommended as healthy (400 µg) and the final concentration of this vitamin in a serving of 50 g is sufficient to assure the WHO-recommended daily intake (Galan et al., 2011d)

Irradiation of Ready-to-eat Sausages containing Lycopene

In recent years the interest in foods with compounds that can have health benefits, such as those containing carotenoids like lycopene, has increased. This work dealt with the manufacture of ready-to-eat (RT E) dry fermented sausages enriched with lycopene. For this purpose, dry-fermented sausages enriched with dry tomato peel (Calvo et al., 2008) were manufactured, sliced, packaged under vacuum and treated with E-beam radiation as non-thermal technology. Doses of 2 and 4 kGy were applied due to demonstrated effectiveness against food borne pathogens as *Listeria* and *Salmonella spp* (Lim et al., 2008; Cabeza et al., 2007, 2009). The effect of this treatment on both the lycopene content and their physico-chemical and sensory properties of these meat products have been studied.

The results showed that doses of 2 kGy are adequate to obtain safe and potentially functional RTE dry fermented sausages enriched with lycopene. These doses no induce relevant physico-chemical or sensory changes, even after 90 days of storage. The final concentration of this carotenoid is sufficient to that 100 g assure the 24% of the intake recommended as healthy. Also, Levels of total viable bacteria, lactic acid bacteria and *Micrococcaceae* decreased as a result of irradiation. Lycopene content was not affected by irradiation and storage. The *b** and the hue angle showed the largest changes of color parameters. The tomato peel modified slightly the texture parameters. Sensory quality was not acceptable in 4 kGy irradiated samples (Gamez et al., 2011).

Effects of irradiation on hamburgers enriched with folic acid

Except for liver and liver-derived products (e.g., paté), meat and meat products cannot be considered a source of folic acid (FA). So far, only a few studies have examined the addition of this vitamin to meat products. For example, Cáceres et al., (2008) carried out a study showing good stability of folic acid in cooked sausage.

The objective of the present work was to manufacture hamburgers enriched with FA in order to create a new meat product with potential functional activity. These hamburgers were treated with ionizing irradiation in order to increase their safety and shelf-life. The effects of this irradiation on the physico-chemical properties and sensory acceptance of the hamburger, as well as on the stability of FA were studied.

Hamburgers enriched with different amounts of FA (0.6, 1.2 and 2.4 mg/100 g) were manufactured. They were then treated with doses of 2-4 kGy of ionizing radiation in order to increase their safety. The effects of these treatments on the color, texture parameters, and sensory quality of the meat, as well as on the stability of FA, were studied in both raw and cooked hamburgers. The presence of FA negligibly influenced the quality of these meat products, with irradiation treatments causing most of the loss of sensory quality and so, the treatment with 4 kGy was not adequate. FA levels decreased 20-30% following irradiation with 2 kGy, and no additional decrease was observed at higher doses of radiation. This new functional meat product may help consumers achieve the recommended daily amounts (RDA) for this vitamin in a normal diet (Galan et al., 2010b).

X-Ray Irradiations

Estimation of NaCl diffusivity by computed tomography in the Semimembranosus muscle during salting of fresh and frozen/thawed hams

The first objective of this study was to develop a simplified, non-destructive methodology based on common diffusion equations and computed tomography (CT) measurements (X-ray density from CT images) for assessing the apparent NaCl diffusion (Ds) in *Semimembranosus* muscle during salting, without interfering with the process. The second objective is to use the developed model to estimate the effect of freezing and thawing treatment, before salting, on the apparent NaCl diffusion (Ds) without interfering with the process under study.

Five pork carcasses were selected according to the *SM* muscle pH (5.8 - 0.1), 24 h post mortem, and hams weight (12.7± 0.5 kg). One ham from each pair was subjected to a freezing/ thawing treatment before salting period. CT images of a central section were taken in each ham during the 16 days of the salting period. From each voxel, NaCl and moisture mass fractions were determined and introduced in the diffusion model. Thus, NaCl apparent diffusion coefficients were calculated for each ham. Resulting diffusion coefficients are in the same order of magnitude than values given by literature. As expected, 30% higher diffusion coefficients were found for frozen/thawed hams samples Combination of calibrated CT measurements with a simple diffusion model can be used to obtain a non-destructive estimation NaCl apparent diffusivity during dry-curing of ham (Picouet et al., 2013).

Salting, drying and sensory quality of dry-cured hams subjected to different pre-salting treatments: Skin trimming and pressing

The dry-cured ham elaboration process consists of a stabilization phase at low temperature, that includes the curing and resting steps, and a following phase of drying-ageing at increasing temperatures.

This study aimed to evaluate the effect of different pre-salting treatments (partial skinning and pressing) on salting, drying and the sensory characteristics of dry-cured hams. With this purpose in mind, the total salt absorption per piece plus the local water activity (a_w), salt and water contents and the product shape throughout the elaboration process were assessed within each piece by computed tomography (CT). Additionally, sensory characteristics of dry-cured hams subjected to both pre-salting treatments were evaluated at the end of the process.

The effects of skinning in a V-shape and pressing of hams on salting, drying and sensory characteristics of dry cured hams were assessed. Salt and water contents and a_w were determined in the central part of the ham during processing by (CT) scan. Overall salt and water contents were also chemically analyzed. Sensory analyses were performed on the final product. Partial skinning or pressing increased both salt uptake and final weight loss, but did not reduce the intra-batch variability in salt uptake. Moreover, trimmed hams exhibited a higher salt content in the inner areas of the hams after resting. Trimmed dry-cured hams showed less metallic flavor, higher saltiness and more mature flavors in the *biceps femoris* muscle, and lower pastiness and adhesiveness as well as higher crumbliness and aged flavor in both the *biceps femoris* and the *semimembranosus* muscles. So, Skin trimming and pressing treatments before salting increased salt absorption but did not reduce the variability in salt uptake within a batch. Trimming in a V shape accelerates the ham weight loss and salt penetration to the innermost parts of hams which could improve microbiological stability during processing and CT scanning could improve the texture and flavor of the final product (Garcia-Gil et al., 2012).

X-ray phase-contrast tomography of porcine fat and rind

This research article demonstrated how grating based phase-contrast CT can provide contrast superior to standard absorption based CT. The method of phase-contrast CT was applied to two samples of porcine subcutaneous fat and rind. The X-ray phase-contrast tomography measurements were carried out using a grating interfero-metric set-up at the ID19 beam-line at the European Synchrotron Radiation Facility (ESRF), in Grenoble, France (Weitkamp et al., 2010). One important feature of the method is that it has been demonstrated in a set-up using a conventional X-ray. This may allow the integration of the method in an abattoir environment.

It was found that grating based X-ray phase-contrast tomography of porcine fat and rind two samples provided a significant increase in the image contrast compared to standard absorption based CT. This increased contrast may be used to investigate the individual fractions of the porcine tissue, such as the fatty acid (saturated, monounsat, polyunsat, Myristic, Palmitic, Palmitoleic, Stearic, Oleic, Linoleic, Linolenic) composition of the fat fraction and the density variations in the rind (The electron densities for different common fatty acids ranged from 0.5 to 5.0%.) It may also be used to obtain a better understanding of fat and rind quality and how treatment influences this. A second possible use of the increased contrast is to use this to reduce the required exposure time. With phase-contrast CT images of sufficient quality it can be obtained a lot faster time than with standard methods due to the increased sensitivity of the method. This will result in a reduction in the dose delivered to the sample, as well as an increase in the capacity (products/second) of the imaging system. The increased speed could be used to integrate online CT into production environments. This method of grating based CT has already been demonstrated with a standard X-ray tube source (Jensen et al., 2011).

Bioaccessibility of Pb from Ammunition in Game Meat Is Affected by Cooking

The *in vivo* digestive uptake of Pb from Pb ammunition fragments embedded in game meat has now been assessed using an animal model (Hunt et al., 2009). However, little work has been published regarding the bioaccessibility (the total soluble fraction of a pollutant) and bioavailability (the proportion of that pollutant actually absorbed into the circulatory system of the organism) of Pb ammunition residues in game meat.

This work, presented an *in vitro* simulation to compare Pb ammunition residue bioacccessibility in game meat cooked with different recipes. The aim was to provide information that may help food quality regulators, that may inform consumers of game meat as to how to reduce their exposure to Pb (*via* changes in cooking practices) and that may be employed to adjust existing theoretical models regarding Pb uptake and subsequent risk in humans.

An *in vitro* gastrointestinal simulation to study bioaccessibility was used in this work. The simulation was applied to meat from red-legged partridge (Alectoris rufa) hunted with Pb shot pellets and cooked using various traditional Spanish game recipes involving wine or vinegar. Total Pb concentrations in the meat were higher in samples with visible Pb ammunition by X-ray (mean ±SE: 3.29 ± 1.12 μg/g w.w.) than in samples without this evidence (1.28 ± 0.61 μg/g). The percentage of Pb that was bioaccessible within the simulated intestine phase was far higher in meat cooked with vinegar (6.75%) and wine (4.51%) than in uncooked meat (0.7%). Risk assessment simulations using these results transformed to bioavailability and the Integrated Exposure Uptake Biokinetic model (IEUBK; US EPA, 2007) showed that the use of wine instead of vinegar in cooking recipes may reduce the percentage of children that would be expected to have > μg/dl of Pb in blood from 2.08% to 0.26% when game meat represents 50% of the meat in diet. Therefore, Lead from ammunition in game meat is more bioaccessible after cooking, especially when using highly acidic recipes. These results are important because existing theoretical models regarding Pb uptake and subsequent risk in humans should take such factors into account (Mateo et al., 2011).

X-Ray phase-contrast tomography of porcine fat and rind

It was demonstrated in this research that grating based X-ray phase-contrast tomography of porcine fat and rind provides a significant increase in the image contrast compared to standard absorption based CT.

As a conclusion this X-ray phase-contrast tomography may be used to investigate the individual fractions of the porcine tissue, such as the fatty acid composition of the fat fraction and the density variations in the rind. It may also be used to obtain a better understanding of fat and rind quality and how treatment influences this. A second possible use of the increased contrast is to use this to reduce the required exposure time. With phase-contrast CT images of sufficient quality can be obtained a lot faster than with standard methods due to the increased sensitivity of the method.

This resulted in a reduction in the dose delivered to the sample, as well as an increase in the capacity (products/second) of the imaging system. The increased speed could be used to integrate online CT into production environments. This method of grating based CT has already been demonstrated with a standard X-ray tube source (Jensen et al., 2011).

Assessment of intramuscular fat level and distribution in beef muscles using X-ray micro-computed tomography

X-ray micro-tomography (μCT), is a nondestructive technique with several advantages compared with other methods, including the ability to image low moisture materials.

This research demonstrated the capability of μCT as a useful technique to quantify intramuscular fat content and to study fat distribution in different breeds and commercial meat joints.

Two different breeds, Podolian vs. Charolaise, were chosen to exhibit variability in terms of visible structure of fat, were used. High Pearson correlation coefficients (r = 0.92-0.99, P < 0.001) were found between fat content, expressed as percentage object volume (POV) determined by μCT and fat content analyzed by an official method.

Useful information was provided from quantitative three-dimensional parameters describing the fat structure, such as the structure model index (SMI), the object structure/ volume ratio (OSVR) and the structural separation (SS). Charolaise breed showed higher POV and SS (P < 0.01) values than Podolian. X-ray micro-tomography allows a rapid estimation of intramuscular fat of meat and provides a more accurate description of the fat microstructure and meat quality.

Comparison of this method with the classical Sox let extraction showed a high correlation between fat contents obtained by both methods in all samples. X-ray micro-tomography allowed a more accurate study of the fat in meat, than the visual appearance. It showed the microstructure of fleck of fat measuring the size, shape, networking/connectivity and distribution of various phases. Although this procedure could appear expensive, X-ray micro-tomography analysis provided more information on the fat content and on its spatial distribution in the sample in order to obtain a more accurate description of meat quality and its expected palatability (Frisullo et al., 2010).

Prediction of salt and water content in dry-cured hams by computed tomography

Application of computed tomography (CT) in meat science is based on the different X-ray attenuations that different tissues produce. X-rays emitted by the CT equipment lose part of their energy when they interact with body tissues, with a different degree depending on the tissue density, as expressed by Beer's law equation:

$I = I_0 \exp(-\mu x)$

where I is the transmitted X-ray intensity, I_0 the incident intensity, x is the sample thickness and μ is the linear attenuation coefficient of the sample.

Attenuation measurements of a sample are collected by CT detectors, located along the gantry, obtaining a matrix of attenuation values also called CT values, which are expressed as Hounsfield units (HU). CT values are defined as the attenuation difference of a given matter (x) relative to water (w) (Kalender, 2005) equation:

$$CT\ \ values\ = \frac{m_x - m_w}{m_w}\ .1000\ HU$$

To the knowledge, H°aseth et al. (2007) were the first to provide a mathematical calibration model between CT values and salt content in dry-cured ham. Furthermore, it was observed that fat and water content highly influenced the precision of the models. When dry samples and samples with visible fat were included in the model, the prediction error was 1.3% NaCl, whereas excluding dry or fat samples reduced the prediction error to 1% and 0.8% NaCl, respectively. The lowest prediction error (0.3% NaCl) was obtained when predicting salt in lean and not dry samples. Nevertheless, these studies were performed in 22 model samples and only 4 real hams. A thorough study of the effects of different fat and drying levels in real ham samples has not been made.

This study developed models for prediction of salt and water contents in dry cured hams with CT by using the combination of various tube voltage settings. The influence of fat content and drying level on the accuracy of the prediction of both salt and water content are evaluated.

Therefore, salt diffusion and distribution can be easily followed throughout the process. In this study prediction models for salt (RMSECV = 0.3% NaCl) and water content (RMSECV = 1.5% water) in non fatty areas of dry-cured hams at the initial stages of the process, which proved useful for control purposes, were achieved. The combination of two tube voltages, 80 kV and 120 kV, significantly improved the precision of the models when fatty or dry samples were included. Since fat content and drying level of the hams significantly affected the salt and especially the water content prediction, specific models for each group should be developed. So, CT can be considered as a useful tool for characterizing and optimizing the industrial salting processes in the meat industry (Fulladosa et al., 2010).

Lean content prediction in pig carcasses, loin and ham by computed tomography (CT) using a density model

This work to aimed validate with a significant number of samples (N=122) a simple methodology based on both computed X-ray tomography (CT) image scans and densities of the different tissues to estimate pig carcass weight as well as to determine the lean meat content in pig carcasses. Another objective was to provide a non invasive methodology, for Spanish pig's processor, to estimate lean content invaluable pieces (ham and loin) for further drying process or commercialization.

Pig carcasses (122 half carcasses, 52 hams and 52 loins) from the Spanish pig population, were obtained in a commercial slaughterhouse and scanned by computed tomography to generate a predictive model determining weight and lean content. The model is mainly based on a density correction equation. The weight prediction model used the area of the histogram of the whole half carcass in a range of −250 to +800 Hounsfield units added to 2769 g corresponding to the average weight of the head and pig feet that have not been scanned.

The lean content predictive model is based on the ratio between the area of the lean peak in the calculated histograms and the area of the histogram of the whole half carcass. Both models were correlated with a manual dissection of the samples. Results of the predictive models and from the dissection were compared with the calculation of the root mean square error of calibration (RMSEC) for weight determination and lean content. Results showed that a RMSEC of 0.6 kg can be obtained for the weight half carcass. For prediction of the lean meat percentage a RMSEC of 1.48% can be obtained for the carcasses, 0.97% for the ham and 1.07% for the loin. According to the obtained results, with a simple methodology it was possible to have good prediction values of weight and lean % in accordance with EU regulation (Picouet et al., 2010).

Simple and Rapid Determination of Phosphorus in Meat Samples by wavelength dispersive WD-X Ray Fluorescence Method

The X-ray fluorescence (XRF) method offers a possibility of quantitative determination of some analytes in the solid samples. This method is convenient for determination of such elements, for which the reliable wet chemical methods are unavailable, as well as for analysis of non-metallic specimens.

This work dealt with the determination of total phosphorus content in meat samples by the wavelength dispersive X-ray fluorescence (WD-XRF) method and compared to the standard UV-vis method of meat analysis. The latter technique is time consuming due to the sample preparation (mineralization or extraction procedure).

The wavelength dispersive X-ray fluorescence (WD-XRF) method for phosphorus determination in meat samples was described and the effects of sample pretreatment on the XRF analysis was discussed. The phosphorus content determined in meat samples ranged from 603 ± 6 to 613 ± 19 mg P/100g dry mass (d.m.), depending on the sample preparation technique. The meat samples spiked with phosphates have been used for the calibration procedure. The accuracy was determined against a number of certified reference materials (Smrd 2000, RF 8414, NIST-1568A, and NIST-1549), and recovery was assayed using the standard addition procedure. The proposed method has been compared with the standard spectrophotometric method (PN-ISO 13730, 1999) of total phosphorus determination. The sample pretreatment procedure has been reduced to minimum. The presented results suggested that the WD-XRF method can be an alternative to the spectrophotometric analysis. This method has been recommended as simple, precise, accurate and easy to apply in a meat laboratory (Jastrzbska et al., 2010).

Predicting beef cuts composition, fatty acids and meat quality characteristics By spiral computed tomography

CT scanning of meat may capture the changes of tissue densities and properties and therefore improve the predicting ability of CT data for both composition and quality traits compared to measurements in the live animal. In the case of beef, moderate to low phenotypic correlations were found between average CT muscle density of beef primals and IMF in a preliminary study by Navajas et al. (2010). To the best of the knowledge, there are no studies testing the use of SCTS to predict quality parameters of beef using a multivariate analysis.
This research investigated the using of a multivariate approach, the potential of SCTS scan tissue density values as predictors of beef cuts composition and beef quality characteristics in crossbred cattle. Beef quality traits included were technological parameters, eating quality traits, fatty acid profile and intramuscular fat content.
X-ray computed tomography (CT) as a predictor of cuts composition and meat quality traits using a multivariate calibration method (partial least square regression, PLSR) was investigated in beef cattle. Sirloins from 88 crossbred Aberdeen Angus (AAx) and 106 Limousin (LIMx) cattle were scanned using spiral CT. Subsequently, they were dissected and analyzed for technological and sensory parameters, as well as for intramuscular fat (IMF) content and fatty acid composition.
The results of CT-PLSR calibrations, tested by cross-validation, were able to predict with high accuracy the subcutaneous fat, inter-muscular fat, total fat and muscle content in AAx and LIMx samples, respectively.
However, low to very low accuracies were obtained for technological and sensory traits with R^2 ranged from 0.01 to 0.26. The image analysis evaluated provided the basis for an alternative approach to deliver very accurate predictions of cuts composition, IMF content and fatty acid profile with lower costs than the reference methods (dissection, chemical analysis), without damaging or depreciating the beef cuts, were able to predict with high accuracy the subcutaneous fat (R^2, RMSECV=0.94, 34.60 g and 0.92, 34.46 g), inter-muscular fat (R^2, RMSECV=0.81, 161.54 g and 0.86, 42.16 g), total fat (R^2, RMSECV=0.89, 65.96 g and 0.93, 48.35 g) and muscle content (R^2, RMSECV=0.99, 58.55 g and 0.97, 57.45 g) in AAx and LIMx samples, respectively. Accurate CT predictions were found in fatty acid profile (R^2=0.61–0.75) and intramuscular fat content (R^2=0.71–0.76) in both sire breeds (Prieto et al., 2010).

Levels of 2-Dodecylcyclobutanone in Ground Beef Patties Irradiated by Low Energy X-Ray and Gamma Rays

Although irradiation is very effective at eliminating food pathogens, acceptance and commercial adoption of food irradiation is still low because of the formation of 2-alkylcyclobutanones (2-ACBs) in irradiated, lipid-containing foods.
The objectives of this study were to measure and compare the level of 2-Dodecylcyclobutanone (2-DCB) in ground beef patties irradiated with low-energy X-rays and gamma rays. Thus, Beef patties were irradiated with low-energy X-rays and gamma rays (Cs-137) at 3 targeted absorbed doses of 1.5, 3.0, and 5.0 kGy.
The samples were extracted with *n*-hexane using a soxhlet apparatus, and the 2-DCB concentration was determined by gas chromatography-mass spectrometry. The 2-DCB concentration increased linearly ($P < 0.05$) with irradiation dose for gamma-ray and low-energy X-ray irradiated patties. There was no significant difference in 2-DCB concentration between gamma-ray and low-energy X-ray irradiated patties ($P > 0.05$) at all targeted doses.
Therefore, these results indicate that 2-DCB formation in irradiated ground beef is independent on the energy level or the type of the irradiation source (Hijaz and Smith, 2010).

CONCLUSION

Ionizing radiation includes gamma rays, electron beams, and x-rays. It has excellent potential, particularly in achieving quality improvements in meat and meat products processing. Ionizing radiation is very effective at eliminating food pathogens. Low-dose (<10 kGy) irradiation can kill at least 99.9% of *Salmonella* in poultry and an even higher percentage of *E. coli* O157:H7. E-beam irradiation is well known to be more effective than gamma-ray irradiation in decreasing *B. cereus* and *E. coli* O157:H7, but not for *L. monocytogenes*. Combining several intervention technologies such as low-dose irradiation and antimicrobials is a promising technology to ensure the safety of RTE meat products against *L. monocytogenes* without sacrificing the quality of RTE meats. Stability of folic acid and lycopene contents as well as the physicochemical properties, microbiological counts, color, texture and sensory properties of dry fermented sausages have been realized by E-beam radiation. Gamma irradiation in combination with antioxidant addition (tea poly-phenol) was used in the pork industry to produce a prime quality product with prolonged shelf-life. X-ray irradiations e.g. computed and micro-computed tomography can be used successfully for prediction assessment and estimation of salt and water content in dry-cured ham, sodium chloride diffusivity of fresh and frozen/thawed ham muscles during salting and intramuscular fat level and distribution in beef muscles.

Abbreviations

CFU	Colony-Forming Unit	SRD	Simulated Retail Display
MDCM	Mechanically Deboned Chicken Meat	CT, μCT	Computed Tomography, Micro-computed tomography
MDA	Muscular Dystrophy Association	SCTS	Spiral Computed Tomography Scan
VIP	Visual Immuno Precipitate	DXA	Dual-energy X-ray Absorption
ELISA	Enzyme-linked Immuno sorbent Assay	WBSF	Warner–Bratzler shear force
RTC	Ready-To-Cook	2-ACBs	2-alkylcyclobutanones
HACCAP	hazard analysis and critical control points	2-DCB	2-Dodecylcyclobutanone
DFE	Dietary Folate Equivalents	RMSECV	Root Mean Square Error of Cross-Validation
DTP	Dried Tomato Peel	SPME	Solid-phase micro-extraction
TPC	Total Aerobic Plate Count	EPR	Electron Paramagnetic Resonance
MeV	MeV and meV are multiples and submultiples of the electron volt unit	COPs	Cholesterol oxidation products
kGy	Kilogray is a radiation absorbed dose	R^2	Coefficient of determination in calibration; R = Correlation Coefficient
^{234}Ur	Uranium-234 is an isotope of uranium		

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