OPEN ACCESS

Edited by:
Victor Hugo Gomes Sales,
Federal Institute of Amapá,
Macapá, Brazil

Section:
Food Science and Tecnhonology - Review, a section of the Journal of Bioenergy and Food Science

ID JBFS2572018

DOI 10.18067/jbfs.v5i4.257

Implications of the use of irradiation in the processing of animal origin foods: Review

Implicações do uso da irradiação no processamento de alimentos de origem animal: Revisão

[1,*] Marta Maria Braga Baptista Soares XAVIER, [1] Robson Maia FRANCO, [2] Mauro Carlos Lopes SOUZA, [3] Sheila da Silva DUQUE and [3] Wagner Thadeu Cardoso ESTEVES

[1]Faculdade de Veterinária, Universidade Federal Fluminense/ UFF. Rua Vital Brazil, nº. 64, Santa Rosa, Niterói, Brasil. CEP: 24230-340.

[2]Laboratório de Instrumentação Nuclear, Centro de Tecnologia (CT), Universidade Federal do Rio de Janeiro/ UFRJ. Bloco I, sala I-133, Ilha do Fundão, Rio de Janeiro, Brasil. CEP: 21941-972.

[3]Laboratório de Zoonoses Bacterianas, Coleção de Campylobacter, Instituto Oswaldo Cruz, Fundação Oswaldo Cruz. Avenida Brasil, nº. 4365, Manguinhos, Rio de Janeiro, Brasil. CEP: 21040-360.

*Correspondence:
Marta Maria Braga B. S. Xavier
m2b2sx@hotmail.com

Competing interests
The authors have declared that no competing interests exist.

Funding:
The authors have no support or funding to report.

Invited: October 09, 2018

Received: November 15, 2018

Accepted: November 28, 2018

Published: December 01, 2018

Citation:
Xavier, M. M. B. B. S., Franco, R. M., Souza, M. C. L., Duque, S. da S., & Steves, W. T. C. (2018). Implication of the use of radiation in the processing of animal origin food: Review. *Journal of Bioenergy and Food Science*, *5*(4), 131-144. doi: 10.18067/jbfs.v5i4.257

ABSTRACT

Food irradiation has been used since the early twentieth century. It has become a safe method of animal food preservation, mainly by keeping their sensory and nutritional characteristics intact, reducing economic losses and increasing products durability. The technique can effectively eliminate or reduce foodborne microorganisms, parasites and pests without significant impact and change in composition, ensuring food safety and nutritional quality. Irradiation is currently used in meat and chicken giblets, beef, dairy products and other animal products. There is a growing consumer demand for nutritious and safe food worldwide. At the same time, contamination by microorganisms, especially of animal origin, remains a major public health problem, causing a significant increase in foodborne diseases, and thus affecting the productivity of human populations. The energy involved in irradiation is not powerful enough to affect the nucleus of the atoms within the food and, since the food does not come into contact with the radioactive source, it does not become radioactive. The process involves exposing the food, either packaged or in bulk, to carefully controlled amounts of ionizing radiation for a specific time to destroy pathogenic microorganisms. The limitation of this process concerns consumer acceptance, because they associate irradiation with radioactivity. Therefore, the present study aimed to clarify the practical benefits of food irradiation associated to a food preservation system, through a systematic literature review.

Keywords: Food irradiation. Preservation. Microorganisms. Public health.

RESUMO

A irradiação de alimentos vem sendo utilizada desde o início do século XX. Tem se tornado uma alternativa segura na conservação dos alimentos de origem animal, principalmente por manter intactas suas características sensoriais e nutritivas, reduzindo perdas econômicas e aumentando a validade dos produtos. É uma técnica eficiente, capaz de eliminar ou reduzir micro-organismos, parasitas e pragas, sem causar perdas significativas à composição dos alimentos, garantindo sua qualidade, inocuidade e segurança nutricional. Atualmente utilizada em carne e miúdos de frango, carne bovina, produtos lácteos, entre outros. A demanda dos consumidores por alimentos nutritivos e higienicamente seguros vem crescendo mundialmente. Ao mesmo tempo, a contaminação por micro-organismos, especialmente os de origem animal, continua a ser o maior problema de saúde pública, ocasionando considerável aumento das doenças alimentares, e afetando consequentemente, a produtividade das populações humanas. A energia envolvida na irradiação de alimentos é insuficiente para alterar os núcleos atômicos do material irradiado e, como esse último não entra em contato com a fonte radioativa, o alimento não se torna radioativo. O processo consiste na exposição dos alimentos, já embalados ou a granel, a um campo de radiações altamente penetrantes por um determinado tempo com o objetivo de destruir micro-organismos patogênicos. A limitação do seu uso está relacionada à aceitação pelos consumidores, por associarem a irradiação com radioatividade. Entretanto, campanhas educativas são ferramentas eficientes para divulgar as diferenças entre os conceitos e modificar as opiniões sobre a aceitação dos alimentos irradiados. Neste contexto o presente trabalho teve por objetivo apresentar em forma de revisão bibliográfica, os benefícios práticos quando associada à um sistema estabelecido na conservação dos alimentos.

Palavras-chave: Irradiação de alimentos. Conservação. Micro-organismos. Saúde coletiva.

INTRODUCTION

Research on food irradiation dates back more than 100 years. In the United States, the Massachusetts Institute of Technology (MIT) has been conducting studies in this field since 1889. In Europe, research on food irradiation began in 1914. After 1950, further studies revealed the benefits associated to the use of the food irradiation process. Between 1964 and 1997, The World Health Organization (WHO), in association with the United Nations Food and Agriculture Organization (FAO) and the International Atomic Energy Agency (IAEA) monitored the findings of several studies. In the latest meeting of this group, in 1997, food irradiation at a maximum dose of 10 kGy was recommended, without the need for toxicological or nutritional tests. These doses do not affect food sensory characteristics. Irradiated food consumed worldwide is not subjected to doses higher than 10 kGy. Thus, the use of irradiation in food was approved by health authorities of 40 countries.

On January 26, 2001, the Brazilian National Surveillance Agency (ANVISA), through its Resolution RDC no. 21, established new regulations for irradiated food, revoking the former ordinances. This legislation is considered the most advanced in the world, and irradiation is defined as the physical process of treatment where food, either packaged or in bulk, is exposed to carefully controlled amounts of ionizing radiation, for sanitary, phytosanitary or technological purposes, and the minimum adsorbed dose should be sufficient to achieve the desirable objective, and the maximum dose should be lower than the dose that impairs functional properties and sensory attributes of the food.

Food industries use several methods of food preservation such as cooling, freezing, dehydration, fermentation, addition of chemical preservatives, among others. These procedures prevent or inhibit growth of microorganisms, in order to ensure high product quality, by enhancing the product safety and extending the validity period. Other methods eliminate microorganisms, such as pasteurization, sterilization and irradiation. Regarding food irradiation, the most common process is ionizing radiation. Irradiation is also known as cold pasteurization and can be used in the prevention of foodborne diseases, especially caused by foods, especially in raw or partially processed foods. The main advantage of this process is that it causes minimum changes in the food and/or its components, unlike other products such as freezing or cooking.

Irradiation is an effective technique of food preservation, since it eliminates or reduces pathogens, parasites and pests without significant impact on food composition, ensuring its safety. It can be widely used in animal food.

The present study, which was based on systematic review of the literature on food irradiation, aimed to assess its application as a safe method of animal food preservation.

THE TECHNOLOGY OF FOOD IRRADIATION

Food irradiation has a 100-year history, but it has been developed and adopted as a food processing technology in the second half of the twentieth century (Molins, 2001).

According to Diehl (1995) and Ham et al. (2017) the main types of ionizing radiations are alpha, beta, gamma, X rays and neutron particles. It is a non-thermal food processing method. It is the process of exposure of food materials to controlled amounts of ionizing radiations, such as particles (alpha, beta and neutron particles), as well as high frequency electromagnetic waves (gamma radiation and X-rays). Alpha radiation is identical to the nucleus of a helium atom and cannot penetrate a sheet of paper. Beta radiation is consisting basically of more penetrating electrons, but cannot pass through a foil, while gamma radiation is highly penetrating and can pass through a thin sheet of lead. Neutrons are high-energy particles with great penetrating power that can produce radioactive elements, and this process is called activation. For this reason, they are not used in food irradiation. X-rays are relatively less penetrating than gamma radiation, and have one inconvenience: low energy efficiency, since only 3 to 5% of the energy applied is effectively converted into X-rays.

The Importance of gamma radiation that is generally used in the food industry was quoted by Ayari et al. (2016), Shah, Mir and Pala (2014). This tool effectively interrupts the biological processes to improve the safety and microbiological stability of food. The safety and consumption of irradiated food have been extensively studied at the national and international levels, and the authors concluded that foods irradiated by appropriate technologies are safe and nutritionally adequate. Specific applications of food irradiation were approved by national legislations of more than 55 countries worldwide.

LEVELS OF APPLICATION AND THEIR EFFECTS

The international unit of measure of irradiation dose is Gray (Gy) or kilo-Gray (kGy), where 1 Gray = 0.001 kGy = 100 rads = 1 J / kg (energy absorbed per kilogram of irradiated food). The international unit of measure of irradiation dose is Gray (G) or kilo-Gray (kGy), where 1 Gray = 0.001 kGy = 100 rads = 1 J / kg (energy absorbed per kilogram of irradiated food). Depending on the dose used, irradiation can double or triple the shelf life of food products, allowing their transport over long distances and fight contamination caused by poor hygiene during processing of meats – eliminating pathogens of animal origin. Irradiated foods can be eaten immediately after processing and irradiated ready-to-eat food that require no refrigeration can be stored for years, such as meals prepared for astronauts (Empresa Brasileira de Radiações, 2005, Vital, 2005).

The use of low doses (< 1 kGy) inhibit budding, ensuring long-term storage, without the need for chemical budding inhibitors; control of insects by sexual sterilization, thus preventing losses in cereal grains, wheat, dried fruits, nuts and legumes stored without the use of chemical pesticides; prevention of the spread of insect pests in food trade; use in quarantine treatment (Germano & Germano, 2008).

With the use of medium radiation doses (1 kGy – 10 kGy) there is decrease and elimination of populations of bacteria, fungi and parasites present on food surface and internally, thus favoring longer preservation, and preventing foodborne diseases caused by several pathogens e.g. *Salmonella* spp., *Shigella* spp., *Campylobacter* spp., *Yersinia* spp., *Enterococcus* spp., *Escherichia coli* (Alves, Pimentel & Franco, 2012; Barcellos et al., 2016; Henry et al., 2010; Santos et al., 2006; Sivinski and Switzer, 1985; Xavier et al., 2011; Xavier et al., 2016).

However, the use of high irradiation doses (10 kGy – 45 kGy) eliminates the populations of several microorganisms that promote the deterioration of food and destruction of pathogens, including spore formers such as *Clostridium botulinum* that cause foodborne diseases and damage to public health (Fellows, 2006).

Irradiation may induce the formation of some substances called radiolytic products in food composition. These substances are not radioactive and are not exclusively found in irradiated foods. Many of them are naturally found in foods or produced during the heating process (glucose, formic acid, carbon dioxide). Studies on these substances did not find association between their presence and harmful effects to humans. This irradiation has little impact on nutrients (Gava, 2008).

Other food preservation processes such as heating may cause much significant reduction in nutrients. Vitamins are very sensitive to any type of processing. It is known that vitamin B1 (thiamine) is particularly susceptible to irradiation. Nonetheless, nutrient losses are minimal. Under irradiation, vitamin C (ascorbic acid) is converted into dehydroascorbic acid (another active form of vitamin C) (Mello, 2000).

The radiation sources used in the process of food irradiation promote ionization, i.e. create positive or negative charges. Such ionization results in chemical and biological effects that block cell division in bacteria, through the rupture of their molecular structure. The levels of energy used to obtain this effect are not sufficient to induce radioactivity in the foods. Under no circumstances, the food comes into contact with the radiation source (Vital, 2005).

The process of irradiation can be chemically understood as follows: ionizing radiations pass through food, there are collision between the ionizing radiations and food particles at the atomic and molecular levels. The production of electron pairs occurs when the energy of these collisions is sufficient to displace one electron from its orbit. Molecular changes occur when such collisions provide enough energy to break chemical bonds between the atoms, leading to the formation of free radicals. Because of their unpaired electrons, free radicals are highly chemically reactive towards other substances, or even towards themselves in an attempt to regain stability. This reaction of free radicals is the basis for the mechanisms through which microorganisms, enzymes and food constituents are changed during irradiation (Fellows, 2006).

The entire process that leads to final stable products as a result of irradiation of a medium is called radiolysis. Also, radiolytic products are the products resulting from primary and secondary effects of irradiation. This process occurs in fractions of microseconds. Because some final products are not stable, post-irradiation effects may occur in some systems for days or months. It should be noted that free radicals occur not only in irradiated products. Several biochemical reactions in plants and animals, as well as drying and heat produce free radicals (Vital, 2005).

Damodaran, Parkin and Fennema (2010) reported that water is present in almost all foods. Thus, water radiolysis is particularly important in food irradiation. When pure water is irradiated, the radiolytic products formed are hydroxyl radical (OH), aqueous electron (e-aq); Hydrogen atom (H); Hydrogen (H_2); Hydroxide peroxide (H_2O_2); and hydrated proton (H_3O^+).

According to the WHO, foods irradiated with doses up to 10 kGy do not require toxicological or nutritional assessment. This is the maximum dose used in the irradiated foods consumed worldwide. Specialists assure the safety of irradiated foods for consumers, for product and equipment handlers and for the environment, as long as there is compliance with the maximum limits of irradiation (specific for each product) and the basic standards of operational safety. Irradiated food does not become radioactive (Miranda & Xavier, 2012).

MICROORGANISMS, IRRADIATION AND CONCERN WITH CONSUMER HEALTH

Several factors contribute to the effectiveness of irradiation, including the group and species of microorganism, the amount of microorganisms in the sample, the presence or absence of oxygen, the physical aspect of the food, the stage of pathogen growth and the food product composition, initial quality of raw material (Jay, 2005, Xavier et al., 2011).

Radio resistance index is the D10-value (1Gy = 1 Joule/kg) defined as the dose necessary to inactivate one log cycle (90%) of a given population. Resistance is related to various factors such as temperature, medium where the pathogen is (more or less complex such as a liquid medium, for example), atmosphere, types of cells (Gram-positive or Gram-negative cells), biological age of cells (Urbain, 1986).

Leitão (1988) emphasized some characteristics of the microorganisms: Gram-negative bacteria, including deteriorating bacteria, are more sensitive than Gram-positive bacteria; Among Gram-positive bacteria, those of genera *Deinococcus* and *Rubrobacter* have the highest radio resistance index. Among Gram negative bacteria, those of genera *Acinetobacter* and *Moraxella* are the most resistant to irradiation. The resistance of Gram-positive bacteria is not fully understood. It is believed that this is due to the presence of a more complex cell envelope, of pigments and nucleic acid repair mechanisms. Bacterial spores and yeasts are much more resistant, while mold has a behavior similar to that of vegetative cells of bacteria.

In 1985, Sivinski and Switzer determined that low irradiation doses, between 0.3 kGy and 1.0 kGy inactivated the parasite *Trichinella spiralis* in pork and that dose of 1.0 kGy in pork packed in vacuum stored up to 21 days at 4°C decreases the number of mesophilic, psychrotrophic and *Staphylococci* spp. during storage of meat.

Regarding the findings related to reduced bacteriological presence in irradiated chicken breast, Lescano et al. (1991), Spoto et al. (1999) and Oliveira et al. (2009) found that the use of irradiation technology at various doses effectively reduces the microbial population in chicken and its products.

Kvernberg (1991) used the irradiation process in fish fillets (*Lophius gastrophysus*) refrigerated and stored at 0°C to observe the effect of gamma radiation at doses of 3.0 kGy, 5.0 kGy and 7.0 kGy and obtained the reduction of 6.7 log CFU/g on aerobic psychrotrophic heterotrophic bacteria.

Clavero et. al. (1994) investigated the sensitivity of pathogenic agents such as *Escherichia coli* O157: H7, *Salmonella* spp. and *Campylobacter jejuni* in minced meat subjected to irradiation by gamma rays (Co_{60}), with doses ranging from 0 to 2.52 kGy. These pathogenic agents were found to be highly sensitive to gamma irradiation.

The experiment conducted by Miyagusku et al. (2003) with irradiation of chicken breasts at maximum doses of 7 kGy caused a significant decrease in the microbiota.

The experiment performed by Santos et al. (2003) aimed to determine the dose of gamma radiation needed to reduce the population of *Salmonella* spp. in chicken meat. The results allowed to recommend the minimum dose of 3.8 kGy for irradiation of chicken drumsticks, in order to obtain a product suitable for human consumption regarding the presence of *Salmonella Typhimurium*.

The influence of gamma radiation in the ripening period of "Prato" cheese it was analyzed by Gutierrez et al. (2004). The cheese was ripened at 10-12°C and at ± 80% RH for 60 days. At the 1st and at 15th day of ripening, sample were irradiated to 0 (control), 1, 2, 3 and 4kGy at a rate of 0.9696kGy/h, the cobalto-60 source used was a Gamma beam 650 from Atomic Energy of Canada. Microbiological characteristics were analyzed each 15 days of ripening. The results showed that the total microbial count decreased as increased the dose of irradiation of the cheese. The ripening of the cheese was delayed by irradiation, probability due to the inactivation of the lactic bacteria by radiation.

Using the irradiation process in the research, Valente et al. (2004) observed the efficiency of gamma radiation in reducing the bacterial load of *Escherichia coli*, both for samples of mussels irradiated with 3.0 kGy and for samples irradiated with 5.0 kGy.

Pinto et al. (2005) examined the effect of irradiation with gamma rays using the dose of 3.0 kGy in chicken breast monitored by the count of aerobic mesophilic heterotrophic bacteria and obtained a considerable reduction in the number of microorganisms.

In the study carried out by Santos et al. (2007), with ostrich (*Struthio camelus*) thighs, were cross-sectioned, frozen packaged, submitted to the gamma irradiation process at 1.0 kGy and 3.0 kGy doses, bacteriological analyzes performed at 5, 120, 240 and 360 days for psychrotrophic and *Enterococcus* spp. Initially, the results obtained showed a reduction of psychrotrophs and *Enterococcus* spp., but during storage obtained high values in the enumeration of *Enterococcus* spp. The author found that the irradiation process was an effective food preservation method.

Abreu et al. (2008) used gamma radiation in fillets of Long lure frogfish (*Lophius gastrophysus*) cooled and stored at 0°C to observe the effect of irradiation with gamma rays at doses 3.0 kGy, 5.0 kGy and 7.0 kGy, and obtained a reduction of 6.7 log Colony Forming Unit/g of aerobic heterotrophic bacteria.

This work carried out by Calixto et al. (2009) had evaluated the efficiency of irradiation in the conservation of meat samples of *Dorytheutis plei* (Blainville, 1823). Its main aim was to study the effects of the exposure to gamma radiation on the microbiological stability of frozen squid rings. Twenty-four selected samples were grouped according to the absorbed dose: 0 kGy (control), 1.5 kGy and 3.0 kGy. The monitoring of the samples throughout the storage time was undertaken by microbiological (aerobic mesophilic and psychrotrophic bacteria count) analyses.

Fernandez et al. (2009) conducted a study on the effect of gamma radiation on triceps brachii muscle of boar (*Sus scrofa*) and Alves, Pimentel and Franco (2012) observed the effect of gamma radiation on "Santa Inês" lamb cooled meat using the technique of enumeration of *Enterococcus* spp., in both studies, the efficiency of the irradiation process was observed with the reduction in enumeration of the microorganism, but with storage the count was reestablished.

Henry et al. (2010) carried out a study observing the efficiency of the gamma irradiation process with doses of 1.0 kGy and 3.0 kGy in turkey cuts frozen and packed under vacuum during the storage period (5, 180, 360 and 540 days). Bacteriological analyzes were performed with enumeration of *Enterococcus* spp. and count of aerobic psychrotrophic heterotrophic bacteria.

The research conducted by Santos et al. (2010) aimed to investigate the efficiency of gamma irradiation on pre-cooked, frozen, and inspected crab meat (*Callinectes sapidus*). The doses of 3.0 kGy and 5.0 kGy were used, and bacterial enumeration of Enterococcus spp., Counting of mesophilic and psychrotrophic aerobic heterotrophic bacteria was carried out.

In the microbiological analyzes performed by Lírio et al. (2011) in their experiment with honey, they revealed that irradiation doses were enough to significantly reduce the action of *Escherichia coli*, *Aspergillus niger*, *Clostridium esporogenes* and *Paenibacillius larvae*. There was microbial reduction from irradiation with a dose of 5.0 kGy and complete elimination with a dose of 10 kGy. Only for *Paenibacillius larvae*, the dose of 15 kGy was required for total elimination.

Xavier et al. (2011) conducted an experiment with samples of chicken heart (*Gallus gallus*) and analyzed the effect of irradiation with gamma rays (Cs_{137}) at the doses of 1.5 kGy, 3.0 kGy and 4.5 kGy on the control of *Enterococcus* spp. and *Escherichia col*i. In 2016, Xavier et al. reported the effectiveness of irradiation with gamma rays (Co_{60}), using the same doses, the sensitivity of *Enterococcus* spp., *Escherichia coli* and *Campylobacter* spp. in samples of cooled chicken heart (*Gallus gallus*). The results obtained in both experiments showed that the irradiation process reduced the enumeration of *Enterococcus* spp. and *Escherichia coli*, and eliminated *Campylobacter* spp. in cooled chicken heart, making the meat safer for consumption.

The experiment using samples of whole raw milk, in 2015, Silva et al., that were submitted to gamma radiation at the doses of 1.0 kGy, 2.0 kGy and 3.0 kGy, observed the efficiency of the process, in which the dose of 1.0 kGy was sufficient for reduction of 6 cycles for *Escherichia coli.*

The study of Barcellos et al. (2016) aimed to contribute to the assessment of the effectiveness of electron beam irradiation in the increase of commercial validity of cooled corvina fillets, irradiated at 0.7 kGy and 1.0 kGy doses. Electron beams are used in several countries and lead to the destruction of microorganisms by changes in their structures, which occur by removing electrons from their atoms. The fillets were assessed for the Count of Bacteria Heterotrophic Aerobic Mesophilic (CBHAM) and Count of Bacteria Heterotrophic Aerobic Psychrotrophic (CBHAP) and enumeration of *Enterococcus* spp. It is concluded, thus, that the use of the irradiation technology effectively reduces the growth of the three groups of bacteria investigated and increases the commercial validity of the referred fish.

The effect of gamma irradiation on microbial load of minced beef meat has been evaluated in the research conducted by Khalafalla et al. (2018). Minced beef meat was irradiated using a Co_{60} irradiation source at 2.0 kGy, 4.0 kGy, 6.0 kGy, 8.0 kGy and 10 kGy gamma irradiation doses. Irradiated and non-irradiated meat was kept in a refrigerator (4-5°C) for 28 days. Microbiological was done immediately after irradiation and throughout the storage periods at 7 days intervals. The results indicated that all doses of gamma irradiation reduced the total bacterial count, spore forming bacteria, total fungi, *Staphylococcus aureus*, *Salmonella* spp., *Shigella* spp., total coliforms and fecal coliforms in beef meat. Thus, the microbiological shelf-life of all beef meat samples, expect a sample with 2.0 kGy was significantly extended more than 4 weeks (Table 1).

Table 1. Studies conducted by some authors abovementioned related to the study and control of microorganisms in animal products, with the use of irradiation process.

Type of radiation	Dose (kGy)	Microorganisms studied	Products of animal origin	References
Gamma / Co_{60}	3.0, 5.0, 7.0	CBHAP	Long lure Frogfish	Abreu et al. (2008)
Gamma / Cs_{137}	3.0, 5.0	CBHAP, *Enterococcus* spp.	Lamb	Alves, Pimentel & Franco (2012)
Eletron Beans	0.7, 1.0	CBHAP, *Enterococcus* spp.	Corvine	Barcellos et al. (2016)
Gamma / Cs_{137}	1.5, 3.0	CBHAM, CBHAP,	Squid rings	Calixto et al. (2009)
Gamma/ Co_{60}	0.175 to 2.52	*E.coli* O157:H7, *Salmonella* spp., *Campylobacter jejuni*	Minced meat	Clavero et. al. (1994)
Gamma / Co_{60}	2.0, 4.0	CBHAP, *Enterococcus* spp	Boar	Fernandez et al. (2009)
Gamma/ Co_{60}	1.0, 2.0, 3.0, 4.0	Total count, Yeast and Molds	"Prato" cheese	Gutierrez et al. (2004)
Gamma / Co_{60}	1.0, 3.0	CBHAP, *Enterococcus* spp.	Turkey	Henry et al. (2010)
Gamma / Co_{60}	3.0, 5.0, 7.0	CBHAP	Fish fillet	Kvernberg (1991)
Gamma / Co_{60}	5.0, 10.0, 15.0	*Escherichia coli, Aspergillus niger, Clostridium esporogenes, Paenibacillium larvae.*	Honey	Lírio et al. (2011)
Gamma / Co_{60}	1.5, 3.0, 7.0	CBHAM, CBHAP, Yeast and Molds, Total coliforms, *Escherichia coli, Salmonella* spp	Chicken breast	Miyagusku et al. (2003)
Gamma/ Co_{60}	3.0	CBHAM, Total coliforms, Thermotolerant coliforms, Yeast and Molds, *Salmonella* spp.	Chicken breast	Oliveira et al. (2009)
Gamma / Cs_{137}	3.0	CBHAM	Chicken breast	Pinto et al. (2005)
Gamma / Co_{60}	0.1 to 0.8	*Samonella* spp.	Chicken drumsticks	Santos et al. (2003)
Gamma / Cs_{137}	1.0, 3.0	CBHAP, *Enterococcus* spp.	Ostrich thigh	Santos et al. (2007)
Gamma / Co_{60}	3.0, 5.0	CBHAM, CBHAP, *Enterococcus* spp.	Crab meat	Santos et al. (2010)
Gamma / Co_{60}	1.0, 2.0, 3.0	CBHAM, CBHAP, *Staph. aureus*, *E. coli*	Raw milk	Silva et al. (2015)
Gamma / Cs_{137}	0.3, 1.0	*Trichinella spiralis*	Pork	Sivinsk and Switzer (1985)
Gamma / Co_{60}	3.0, 5.0, 10	*Escherichia coli*, *Enterococcus* spp.	Mussel	Valente et al. (2004)
Gamma / Cs_{137}	1.5, 3.0, 4.5	*Escherichia coli*, *Enterococcus* spp.	Chicken heart	Xavier et al. (2011)
Gamma / Co_{60}	1.5, 3.0, 4.5	*Escherichia coli*, *Enterococcus* spp., *Campylobacter* spp.	Chicken heart	Xavier et al. (2016)
Gamma / Co_{60}	2.0, 4.0, 6.0, 8.0, 10	Total Bacterial Count, Yeast and Molds, *Staph. aureus*, *Salmonella* spp., *Shigella* spp., Total Coliforms and Fecal Coliforms	Raw minced beef meat	Khalafalla et al. (2018)

Source: Authors

LEGISLATION

The process of irradiation was approved by prestigious national and international organizations, both public and private, that support the use of ionizing energy, namely: the "Comissão Nacional de Energia Nuclear" (CNEN), "Agência Nacional de Vigilância Sanitária" (ANVISA), "Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis" (IBAMA), "Companhia Ambiental do Estado de São Paulo" (CETESB), "Ministério da Agricultura Pesca e Abastecimento" (MAPA), Food and Agriculture Organization (FAO), World Health Organization (WHO), United States Food and Drug Administration (USFDA), United Stastes Department of Agriculture (USDA) and United Nations (NU) (Empresa Brasileira de Radiação, 2005).

The advances in the use of irradiation technology have been addressed in several international conferences on public health, microbiological safety, chemical transformations, food irradiation facilities and technology, as well as clarifications to consumers and regulation of products and doses (Miyagusku et al., 2003; Passos and Mendes, 2017; Roberts, 2016).

It should be stressed than 41 countries have a specific legislation on food irradiation. The *Codex Alimentarius* Commission is a joint intergovernmental body of the Food and Agriculture Organization (FAO) of the United Nations and the World Health Organization (WHO), which represents more than 130 countries (Loaharanu, 2003).

In the European Union, Directive 1999/2/EC addresses legislative issues on foods and food ingredients treated with ionizing radiation. The use of food irradiation is not generalized. Licenses were granted only for irradiation of spices and condiments, fruits and vegetables, including tubers; cereals and cereal flakes, fish, shellfish, frog legs, fresh meats, poultry, Camembert made from raw milk; gum arabic, casein/ caseinate, egg white, blood products.

Brazil established a very comprehensive legislation on food irradiation, namely Resolution RDC no. 21 (BRASIL, 2001) of the National Health Surveillance Agency (ANVISA), which approved the Technical Report for Food Irradiation and revoke previous relevant legislations such as "Portaria" no. 09 (Ordinance no. 9) (BRASIL, 1985) and "Portaria" no. 30 (Ordinance no. 30) (BRASIL, 1989). Other food items have been included, because of the permanent interest in the irradiation of several types of foods, studies on this issue are being conducted, and legislation updating is needed.

CONSUMER ATTITUDES TOWARDS IRRADIATED FOODS

Economic and social factors such as cost, availability, food habits, myths associated to lack of knowledge on food irradiation traditionally impact consumer choices. Currently, other factors such as the increase in the number of people eating outside the home and the use of new Technologies are used as decision parameters. Therefore, some clarification is needed on irradiation as another method of food preservation, once its commercial use has been little explored, particularly for export products, due to misinterpretations by consumers (Xavier et al., 2011).

FUTURE PERSPECTIVES OF TECHNOLOGY

Food Irradiation has grown worldwide, according to the growth of food production and demand. The population of the planet grows exponentially. Most countries in the world have built facilities for food irradiation. In Brazil there are already 4 food irradiators, to irradiate foods mainly for export: 1 in Rio de Janeiro, 2 in São Paulo, and 1 in Amazonas. There are several irradiators in Research Institutes and Universities, all over Brazil. Future projections depend on successes between large-scale food producers and the Federal Government.

For some time there has been no progress in the construction and installation of new radiators. It is hoped that there will be an urgent resumption in this direction. But at University and Research Institutions the teaching and work with Food Irradiation proceeds normally.

Throughout the world, the advances in Food Irradiation are always discussed. In Brazil, the current government did not go very far in the discussions. But it is expected that soon the construction of new irradiators will resume.

The biggest food producers in Brazil are very interested in the subject and should give all support to the increase of Food Irradiation, mainly for export.

In any case, it is of the utmost importance that the general public receive information from the government authorities through the ministries related to the subject regarding their use through educational campaigns to elucidate the differences between concepts that consumers still think that the irradiation of food makes it radioactive and harmful to their health with this, modify the parameters regarding the acceptance of irradiated foods, noting that consumers are increasingly demanding in relation to the choice of food and demonstrated great interest in knowing new technologies in to ensure the quality of food.

CONCLUSIONS

From the elaboration of this research can be verified that in Brazil due to deficiency in the monitoring of diseases, as well as the lack of epidemiological information, there is no demonstration of the actual casuistry about how the population is affected by the etiological agents responsible for the diseases of the and food safety, as well as on the safety food consumed.

Of course, health surveillance professionals are expected to be fully committed to check for compliance with/implementation of all the procedures of responsibility of food processing companies and transportation services, as well as of food wholesalers/retailers, to ensure the quality and safety of animal products consumed fresh and their processed byproducts, according to the pertinent legislation.

Food irradiation has become a safe method of food preservation, reducing or eliminating the microorganisms present in foods, including pathogens, and hence reducing social damage (because of the decrease in the number of cases of foodborne diseases) and economic damage (because of the decrease in the percentage of these bacteria in animal foods and byproducts).

More detailed information on the use of this technology is required to elucidate and remove some misconceptions about the safety of food irradiation: some consumers believe irradiated food becomes radioactive and harmful, which is false.

It has been demonstrated that the use of irradiation does not affect the quality of foods, and consequently, is not harmful to public health. Food irradiation is an effective method of food preservation and safety, by reducing or eliminating pathogens. Also, functional and sensory properties of food remain unchanged. Thus, the referred technology contributes to ensure that a greater number of people worldwide have access to safe and nutritious food.

AUTHORS CONTRIBUTIONS

Conducting and evaluating the research: SSD and WTCE; Planning, guidance, drafting and final review of the manuscript: MCLS, EFOJ, RMF

REFERENCES

Abreu, M.G., Freitas, M.Q., Jesus, E.F.O., Clemente, S.C.S., Franco, R.M., & Borges, A. (2008). Caracterização sensorial e análise bacteriológica do peixe-sapo (*Lophius gastrophysus*) refrigerado e irradiado. *Revista Ciência Rural*, *38*(2), 498-503. https://doi.org/10.1590/S0103-84782008000200032

Alves, F.J.X., Silva, T.J.P., & Franco, R.M. (2012). Efeito da radiação gama sobre a contaminação da carne resfriada de cordeiro Santa Inês. *Revista Instituto Adolfo Lutz*, *71*(3), 588-92.

Ayari, S., Han, J., Dang Vu, K., & Lacroix, M. (2016) Effects of gamma radiation, individually and in combination with bioactive agents, on microbiological and physicochemical properties of ground beef. *Food Control*, *64*(1), 173-180. https://doi.org/10.1016/j.foodcont.2015.12.034

Barcellos, C.C.C., Kajishima, S., Souza, M.C.L., & Mesquita, E.F.M. (2016). Avaliação da interferência da irradiação por feixe de elétrons nas características sensoriais de filés de corvina *(Micropogonias furnieri*) refrigerados. *Arquivo Ciências Veterinária Zoologia UNIPAR*, *19*(1), 41-45. https://doi.org/10.25110/arqvet.v19i1.2016.5789

BRASIL. Ministério da Saúde. Resolução RDC no. 21, de 26 de janeiro de 2001. Aprova o Regulamento Técnico para Irradiação de Alimentos, constante do Anexo desta Resolução. Diário Oficial [da] República Federativa do Brasil. Brasília, DF, 29 de janeiro de 2001.

Clavero, M.R.S., Monk, J.D., Beuchat, L.R., Doyle, M.P., & Brackett, R.E. (1994). Inactivation of *Escherichia coli* O157:H7; *Salmonella* e and *Campylobacter jejuni* in raw ground beef by gamma irradiation. *Applied and Environmental Microbiology*, *60*(6), 2069-2075.

Calixto, F.A.A., Franco, R.M., Mesquita, E.F.M., Vital, H.C., & Murayama, E (2009). Avaliação bacteriológica de anéis de lula, *Dorytheutis plei* (Blainville, 1823) (*Mollusca Cephalopoda*), congelados e irradiados. *Revista Portuguesa de Ciências Veterinárias*, *104*(569-572), 71-75.

Damodaran, S., Parkin, K.L., & Fennema, O.R. (2010). Química de Alimentos de Fennema (4ª ed). Porto Alegre: Artmed.

Diehl, J.F. (1995). Safety of Irradiated Foods. New York: Marcel Dekker.

DIRECTIVE 1999/ 2 CE du Parlement Euroupèen et du Conseil du 22/2/99. J. Off. Comm Eur. 13 march, 1999. Directive 1999/2/EC of the European Parliament and of the Council of 22 February 1999 on the approximation of the laws of the Member States concerning foods and food ingredients treated with ionising radiation. Available in: <https://eur-

lex.europa.eu/LexUriServ/LexUriServ.do?uri=CONSLEG:1999L0002:20081211:FR:PDF>. Access in: 2016 February.

Empresa Brasileira de Radiação/ Central Brasileira de Esterilização (EMBRARAD/CBE). Available in: <http://www.cbesa.com.br/tecnologias/>. Access in: 2005 mar.

Fellows, P.J. (2006). Tecnologia do processamento de alimentos: princípios e práticas (2ª ed.). Porto Alegre: Artmed.

Fernandez, A.T., Silva, T.J.P., Franco, R.M., Jesus, E.F.O & Marques, K.C. (2009). Avaliação bacteriológica de carne de javali submetida à irradiação gama durante sua validade comercial. *Revista Higiene Alimentar*, *23*(178/179), 131-140.

Gava, AJ (2008). Tecnologia de Alimentos: princípios e aplicações. São Paulo: Nobel.

Germano, P.M.L., & Germano, M.I.S. (2008). Higiene e vigilância sanitária de alimentos (3ª ed.). São Paulo: Varela.

Gutierrez, E.M.R., Domarco, R.E., Spoto, M.H.F., Blumer, L., & Matraia, C. (2004). Efeito da radiação gama nas características físico-químicas e microbiológicas do queijo prato durante a maturação. *Ciência e Tecnologia de Alimentos*, *24*(4), 596-601. https://doi.org/10.1590/S0101-20612004000400020

Ham, Y.K., Kim, H.W., Hwang, K.E., Song, D.H., Kim, Y.J., Choi, Y.S., Song, B.S., Park, J.H. & Kim, C.J. (2017). Effects of irradiation source and dose level on quality characteristics of processed meat products. *Radiation Physics and Chemistry*, *130*(1), 259-264. https://doi.org/10.1016/j.radphyschem.2016.09.010

Henry, F.C., Silva, T.J.P., Franco, R.M., Freitas, M.Q. & Jesus, E.F.O. (2010). Effect of gamma radiation on frozen turkey breast meat quality. *Journal of Food Safety*, *30*, 615-634. https://doi.org/10.1111/j.1745-4565.2010.00229.x

Jay, J.M. (2005). Microbiologia de alimentos (6ª ed.). Porto Alegre: Artmed.

Khalafalla, G.M., Nasr, N.F., Gaafar, A.M. & Abo-Zaid, R.M. (2018). Effect of gamma irradiation on microbial load, physicochemical characteristics and shelf-life of raw minced beef meat. *Middle East Journal of Applied Sciences*, *8*(2), 625-634.

Kvernberg, J.E. (1991). Nonindigenous Bacterial Pathogens, in Microbiology of Marine food Products Van Nostrand Reinhold, New York.

Leitão, M.F.F. (1988). Tratado de microbiologia. São Paulo: Manole.

Lescano, G., Narvaiz, P., Kairiyama, E., & Kaupert, N. (1991). Effect of chicken breast irradiation on microbiological, chemical and organoleptic quality. *Lebensmittel Wissenschaft und Technologie*, *24*, 130-134.

Lirio, F.C., Vendramini, A.L.A., Souza, M.C.L., & Moura, M.R.L. (2011). Análise Sensorial de Méis Monoflorais Irradiados. *Revista Higiene Alimentar*, *25*(2), 1093-1096.

Loaharanu, P. (2003). Irradiated foods (5ª ed.). American Council on Science and Health.

Mello, L.C. (2000). Alimentos irradiados. *Revista NutriWeb*, *2*(2). Available in: <http://www.nutriweb.org.br/n0202/irradiados.htm>. Access in: 2015 may.

Miranda, Z.B., & Xavier, M.M.B.B.S. (2012). Irradiação de alimentos: mito ou realidade? *Animal Business Brasil*, 2, 56-65. Available in: <https://issuu.com/sociedadenacionaldeagricultura/docs/abb_02>. Access in: 2012 may.

Miyagusku, L., Chen, F., Leitão, M.F.F. & Baffa, O. (2003). Avaliação microbiológica e sensorial da vida útil de cortes de peito de frango irradiados. *Revista Ciência e Tecnologia de Alimentos*, *23*(3), 7-16. https://doi.org/10.1590/S0101-20612003000400003

Molins, R.A. (2001). Irradiación de los alimentos: principios y aplicaciones. Trad. Alberto Ibarz Ribas. Zaragoza: Editorial Acribia.

Oliveira, A.L., Pereira, M.T., Bueno, P.H.S., Oliveira, R.B.P., Pinto, F.C., Correia, R.F., & Machado, M.M. (2009). Qualidade microbiológica da carne de frango irradiada em embalagem convencional e a vácuo. *Arquivo Brasileiro de Medicina Veterinária e Zootecnia*, *61*(5), 1210-1217. https://doi.org/10.1590/S0102-09352009000500026

Passos, F.R., & Mendes, F.Q. (2017). Radiação gama na conservação de carne: uma revisão. *The Journal of Engineering and Exact Sciences*, *3*(6), 763-768. https://doi.org/10.18540/jcecvl3iss6pp0763-0768

Pinto, D.C.C., Mano, S.B., Vital, H.C., Oliveira, L.A.T., Tello, M.V.P., & Pombo, C.R. (2005). Avaliação da irradiação gama em peitos de frangos refrigerados monitorados pela contagem de bactérias heterotróficas aeróbias mesófilas viáveis e pH. *Revista Brasileira Ciências Veterinárias*, *12*(1-3), 37-41. https://doi.org/10.4322/rbcv.2014.325

Roberts, P.B. (2016). Food irradiation: Standards, regulations and world-wide trade. *Radiation Physics and Chemistry, 129*(1), 30-34. https://doi.org/10.1016/j.radphyschem.2016.06.005

Santos, A.F., Vizeu, D.M., Destro, M.T., Franco, B.D.G.M., & Landgraf, M. (2003). Determinação da dose de radiação gama para reduzir a população de *Salmonella* spp em carne de frango. *Revista Ciência e Tecnologia de Alimentos*, *23*(2), 15-19.

Santos, E.R., Pimentel, T.J.S., Franco, R.M., Barbosa, A., & Souza, D.C. (2007). Enumeração, identificação e resistência antimicrobiana de *Enterococcus* spp. em carne de avestruz (*Struthio camelus*) submetida à radiação gama. *Revista Higiene Alimentar*, *21*, 59-63. https://doi.org/10.1590/S0101-20612003000200017

Santos, E.B., Mantilla, S.P., Silva, R.A., Canto, A.C.V.C.S., Nunes, E.S.C.L., Franco, R.M., & Jesus, E.F.O. (2010). Radiação gama na redução da microbiota da carne de siri (*Callinectes sapidus*) pré-cozida, congelada e inspecionada. *Boletim Instituto de Pesca*, *36*(3), 175-183.

Shah, M., Mir, S., & Pala, S. (2014). Enhancing food safety and stability through irradiation: a review. *The Journal of Microbiology, Biotechnology and Food Sciences, 3*(5), 371-378.

Silva, A.C.O., Oliveira, L.A.T., Jesus, E.F.O., Cortez, M.A.S., Alves, C.C.C., Monteiro, M.L.G., & Conte Junior, C.A. (2015). Effect of Gamma Irradiation on the Bacteriological and Sensory Analysis of Raw Whole Milk under Refrigeration. *Journal of Food Processing and Preservation* (On Line), *39*, 2404-2411. https://doi.org/10.1111/jfpp.12490

Sivinski, J.S., & Switzer, R.K. (1985). Low-Dose Irradiation: A Promising Option for Trichina-Safe Pork Certification. Proceedings of Conference on Radiation Disinfestation of Food and Agricultural Products.

Spoto, M.H.F., Gallo, C.K., Alcardi, A.R., Walder, J.M.M., Blumer, L., Domarco, R.E., & Gurgel, M.A.S. (1999). Radiação gama na redução da carga microbiana de filés de frango. *Revista Ciência e Tecnologia de. Alimentos, 19*(3), 397-400. https://doi.org/10.1590/S0101-20611999000300018

Urbain, W.M. (1986). Food irradiation. Orlando: Academic Press.

Valente, A.M., Kasnowsky, M.C., Franco, R.M., Mesquita, E.F.M., Oliveira, L.A.T., Carvalho, J.C.A.P., Freitas, M.Q., & Jesus, E.F.O. (2008). Mexilhões irradiados: Análise sensorial e estudo da sensibilidade antimicrobiana de cepas de *Escherichia coli* e *Enterococcus* spp. *Revista Higiene Alimentar*, *22*(162), 88-95.

Vital, H.C. (2005). Anotações Informais da Disciplina Ensaios Práticos de Irradiação de Alimentos do Curso de Especialização Lato Sensu em Irradiação de Alimentos da UFF, DDQBN/CTEx.

Xavier, M.M.B.B.S., Souza, A.L.M., Xavier, P.M.B.B.S., Vital, H.C., Franco, R.M., & Miranda, Z.B. (2011). Efeitos da irradiação gama em coração de frango resfriado: análises bacteriológicas. *Revista Higiene Alimentar*, *25*(194-195).

Xavier, M.M.B.B.S., Franco, R.M., Souza, M.C.L., Jesus, E.F.O., Fonseca, A.B.M., Duque, S.S., & Esteves, W.T.C. (2016). Effect of Gamma Irradiation in the Control of *Campylobacter* spp. in Chilled Chicken (*Gallus Gallus*) Heart. *African Journal of Microbiology Research*, *10*(6), 1430-1438.