

We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

6,900

Open access books available

185,000

International authors and editors

200M

Downloads

Our authors are among the

154

Countries delivered to

TOP 1%

most cited scientists

12.2%

Contributors from top 500 universities



WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com



Gamma Radiation Effect on Allergenic Food

Marcia Nalesso Costa Harder, Valter Arthur and
Larissa Nalesso Costa Harder

Additional information is available at the end of the chapter

<http://dx.doi.org/10.5772/intechopen.69581>

Abstract

Food allergens are substances that cause an overreaction of the individual immune system of who consumes it. The importance of food allergy in the nutritional present context is increasing, and dietary habits and nutrient availability have rapidly transformed in function of access to consumers. There is no specific treatment for food allergies. It is necessary to stop eating the food. Studies with the use of nuclear radiation to minimize these effects have been performed. The absorption of electromagnetic radiation by the biological tissues that constitute the food produces a function of electronic excitability of the constituent molecules. An example of this reaction is with proteins leading to deamination, breaking peptides, aromatic residues formation, and so on. The extent of these reactions depends on the food conditions and substances that are contained in.

Keywords: ionizing radiation, food irradiation, food allergy

1. Introduction

The use of ionizing radiation was applied in foods given the discovery of radiation at the end of the nineteenth century, since several researches have been carried out in several follow-ups from this unique event for humanity.

Most of the studies on food irradiation describe about the use of technology in microbial control, including the effective and efficient mode of pathogen control, as well as the use to improved post-harvest products.

Mastro [1] explains that the food irradiation reduces the risk of foodborne diseases as has already been established by many studies, and the food thus treated maintains the nutritional value of macrocomponents and suffers loss of microcomponents as is the case with

vitamins. The World Health Organization (WHO) has expressed its views on this, as well as jointly WHO, Food and Agriculture Organization (FAO) and the International Atomic Energy Agency (IAEA). For these international institutions, foods irradiated according to good manufacturing practices (GMP) are safe for consumption and suitable from the nutritional point of view. Irradiated foods are provided for astronauts for years and are the best option for immunosuppressed patients, as well as to meet the emergency food supply during natural disasters.

According to Prejean [2], food security is widely recognized as an increasingly significant public health problem worldwide. For him, regardless of its admitted effectiveness against foodborne pathogens, the employment of irradiation is still rare in the food industry, and the inquiry is as to why a technology that is extremely effective and safe by any scientific test would be greeted with such uncertainty by the food industry.

After exhaustive studies on this topic, recent research has found an alternative use for inosinate radiation using this technology to minimize the allergenic effects of food.

The EACCI [3] defines the allergy as a hypersensitivity reaction begun by immunological mechanisms. The sensitivity can be mediated by antibodies or by cells. In a large number of events, the antibody worthy of the symptoms belongs to the IgE isotype, and the organisms may be mentioned as suffering from an IgE-mediated allergy. Not every allergic response connected with IgE occurs in atopic individuals. In non-IgE-intervened allergy, the antibody may fit into the IgG isotype, for example, anaphylaxis caused by immune complexes holding dextran, as well as in the classical serum disease, previously referred to as type III reaction. Both immunoglobulin E (IgE) and immunoglobulin G (IgG) can be found in allergic bronchopulmonary aspergillosis (ABPA). Allergic contact dermatitis is representative of allergic diseases mediated by lymphocytes.

As advocated by Taylor in the early 1980s, food allergy prevention can be achieved by altering dietary factors responsible for the sensitization and phenotypic expression of the disease. Since then, proteolytic enzyme hydrolysis of allergens and the development of recombinant food with modified DNA have been the hope in the elimination of protein allergens when compared to traditional processing methods [4]. However, these affirmations can be utilized only in limited foods [5].

For now, the structural change of food proteins by radiation was studied by Kume et al. [6], and this result revealed that ionizing radiation could modify antigenicity by the undoing or alteration of conformational and linear epitopes in food allergens [7, 8]. Recently, the complete abolition of intrinsic activity and loss of structural integrity with fragmentation and aggregation following wide-dose irradiation have been observed in several studies [5].

Because of these questions related before, the aim of this paper is to provide some insight into how the peaceful use of ionizing energy can contribute to improve the quality of life of people with some type of food allergy.

2. Ionizing radiation

Harder and Arthur [9] defined radiation as either the transmission or the emission of energy through a material medium or space in the form of particles or waves. Radiation is categorized as

either nonionizing or ionizing. Nonionizing radiation does not have enough energy to completely remove an electron from a molecule or an atom and is ordinarily not harmful to living organisms. It consists of lower ultraviolet, visible light, infrared, microwaves, radio waves, or lower energy electromagnetic waves emitted by power suppliers or receivers for television or radio. By contrast, ionizing radiation does have the energy to liberate electrons from molecules and atoms transforming them into ions. Therefore, ionizing radiation consists of not only ions and atoms but also subatomic particles as well as electromagnetic waves on the high-energy end of the electromagnetic spectrum.

2.1. Gamma ray irradiation

The simplest form of irradiation is gamma ray irradiation. The origin of radiation is a radioactive element that sends protons in the gamma ray reach of the electromagnetic spectrum. Gamma ray photons have a higher recurrence (and hence, energy) than either ultraviolet or X-ray photons. It can permeate a target food to a depth of diverse feet and range of microbial contaminants anywhere within that reach. But it is simple on concept, because in addition to radiating gamma rays, many radioactive elements also produce alpha rays (helium nuclei), beta rays (high-energy electrons or positrons), and/or high-energy neutrons, so it is important to choose well the source of the radiation. Alternatively, they might decay into another radioactive substance that generates these other forms of radiation, but they are undesirable because they have the potential to make the target food radioactive. Gamma rays can be contained by immersion of the source in a sufficient quantity of water, and to prevent inadvertent gamma ray exposure, the source must be insulated from the outside world by several feet of concrete [2, 10].

2.2. E-beam irradiation

For the same authors, E-beam irradiation, even if it uses that identical term as gamma ray irradiation, is a fully different type of treatment. High-energy electron beams are made in an electron gun, a larger version of the cathode ray gun discovered in devices such as televisions and monitors. The electrons can be headed by a magnetic area to aim food. The term “irradiation” is indeed a misnomer, since the food is not stated to electromagnetic radiation or beta rays (electrons made by a radioactive source). Notwithstanding, the development has a resembling effect to that of gamma ray irradiation. E-beam irradiation demands protection as well, but nothing as the concrete box used in gamma ray irradiation. The drawback of the E-beam is its small penetration depth (about an inch), avoiding its use to many foods and restricting the amount of food that can be processed in volume.

2.3. X-ray irradiation

X-ray irradiation is a fairly new technique that matches many of the benefits of the other two processes. As gamma ray irradiation, X-ray irradiation consists of exhibiting food to high-energy photons with a long permeation depth. In this situation, nevertheless, bombarding a metal film with a high-energy electron beam yields the photons, permitting the radiation to be turned on and off. The apparatus is a more powerful version of the X-ray machines used in medical cabinets. The device still demands heavy safeguard, though the amount of protection

required is less than that for gamma ray irradiation. No radioactive material or byproducts are used in, or outcome from, the process [2, 10].

3. Food radiation

The term “food irradiation” refers to any process that exposes food either to electromagnetic radiation or to high-energy particles [2].

Briefly, food radiation is the processing of foods by expounding them to a controlled quantity of ionizing energy for a particular number of times to attain determined technical objectives. Food is irradiated in a particular method facility where it is subject to gamma rays, electron beams, or X-rays. The food is strictly monitored to ensure that the precise dose or treatment levels are performed. When used in this way, irradiation is similar to pasteurization of milk, in that the good is left fresh but much more out of danger.

For Harder and Arthur [11], the principal lead of radiation use in food is a completely default of direct use of chemical elements that may leave residuum in treated food, making it unsuited for consumption. Thus, ionizing radiation used in food attracted interest around the world from many organizations such as the IAEA, FAO, OECD (Organization for Economic Cooperation and Development), and WHO along with the participation of 24 countries in studies to untangle the modifications that are consequences of the use of radiation in the food.

Food radiation is ultimately about how much energy is adsorbed by the mark food. It is important to have a metering for what shot of radiation will be necessary independent of the quantity of food to be irradiated. Radiation doses are calculated in kiloGray (kGy). A portion of 1 kGy shows that the goal specimen receives 1000 J (metric units of energy, for short J) per kilogram of sample bulk. The result of radiation on microbes is measured by a dosage called the *D*-value [12].

The effectiveness of the treatment varies based on the type of radiation used (gamma ray, X-ray, or E-beam), the intensity of the radiation, and the purpose of the use in question.

Irradiation destroys injurious bacteria and other organisms, meat, poultry, and seafood, disinfects spices, spreads shelf-life of fresh fruits and vegetables, and also controls budding in tubers (e.g., potatoes) and bulbs (e.g., onions). As in illustration, a very short number of ionizing energy are worn to expunge insect pests from fruit; a little greater number is used on meat or poultry to destroy noxious bacteria, and notably higher number is used to fully sterilize food. Irradiation complements good manufacturing practices without compromising on food quality or nutrition [13].

For Harder and Arthur [9], there are three different irradiation methods (radappertization, radication, or radurization) used to inactivate microorganisms based on the severity of the process:

- Radappertization is the most severe of the three irradiation methods. With radappertization or sterilization of food, a dose of irradiation is applied that decreases the activity and number of living microbes (excludes viruses) to such a low level that there is no recognized method

for detection. Doses required for radappertization are generally between 25 and 45 kGy [14, 15]. All foods—including eggs without shells in the form of egg white, yolk, or whole egg—subjected to radappertization must be parceled in hermetically sealed packets so that there is no recontamination of the product to the environment. Radappertization is popular for use in meat products such as chicken fillets and turkey breast. The National Aeronautics and Space Administration, the space agency of the United States, uses radappertization to prepare irradiated food for consumption of astronauts during space flights. The irradiated food products have no microbial viability, even at room temperature, provided the package is kept intact. All irradiated foods must have expiration dates regardless of whether the package is kept intact or not because prolonged storage causes chemical and physical changes in these products.

- Radicidation, similar to pasteurization, is the treatment of food with a sufficient dose of ionizing radiation to inactivate nonspore-forming bacteria in a way that the microorganisms are not detected by bacteriological methods normally used on processed foods. Doses required for radicidation are generally between 2 and 8 kGy [14, 15]. Examples of foods where radicidation is applied include juices, fresh meats, fresh pasta, and eggs.
- Radurization is the least severe of the three processes of irradiation with dosages in the range of 0.4–2.5 kGy. Radurization disinfects or sanitizes food and extends shelf-life by causing a reduction in the count of viable spoilage microorganisms. Examples of where radurization is used in foods include the following: (1) preventing the sprouting of bulbs and tubers, (2) preventing the deterioration of fruits and vegetables by fungi, (3) killing parasites, insects, and mites that infest food, and (4) slowing down the ripening of fruits. The delay in ripening and the shelf-life extension in fruits like bananas are great advantages as this fruit can ripen quickly without treatment. The use of radurization to delay the fruit-ripening process provides time for food distribution and exportation.

Other uses with ionizing radiation are the structural alteration of proteins, and it is being investigated as a means of reducing food allergies. Common food allergies in humans include milk β -lactoglobulin, shrimp tropomyosin, and egg albumin. Subjecting food to ionizing radiation changes the antigenicity of food by altering the physical and chemical structure of proteins leading to distortion of the protein's secondary and tertiary structures. Specifically, the epitope area of the food allergen can be modified or destroyed by gamma irradiation so that antibodies to the allergen should never be produced by the individual consuming the irradiated food [9, 16, 17].

The Food and Drug Administration (FDA) [18] treated that for all food submitted to food irradiation, the Radura symbol can be used to identify the process (**Figure 1**), which should be placed on irradiated food packages in many countries of the world. The Radura symbol originated from and was copyrighted by an irradiation food-processing facility located in Wageningen, Netherlands, in the 1960s. The then president Jan Leemhorst of the company called Gammaster recommended its use as an international label to be placed on irradiated food as long as manufacturers implemented appropriate quality parameters. The Radura symbol is listed in the Codex Alimentarius Standard on Labeling of Prepackaged Food. The FDA requires that foods that have been irradiated bear the “Radura” logo along with the statement “Treated with radiation” or “Treated by irradiation”.



Figure 1. The Radura symbol.

3.1. Effects of food radiation

For food irradiation to be safe, radiolytic products (radiolytic products are chemicals created by the interaction of radiation with a substance such as food) must pose no danger for human consumers. Most of radiolytic goods are created by the radiation-rupturing molecular links in water, leaving spare radicals that in turn either recombine into water or interact with other chemicals. Other radiolytic products are created when complex protein molecules are broken into smaller ones. From the standpoint of radiation chemistry, then, irradiation is no more dangerous than cooking food, because radiolytic products formed by food irradiation are all found naturally in non-irradiated food, and the types of compounds formed by irradiation are identical to those formed during the cooking process [19].

Some vitamins, particularly thiamine, undergo an appreciable reduction when exposed to radiation. But in the totality of the diet, however, FDA determined that the average person's intake of these vitamins would be well above the recommended dietary allowance (RDA) [19].

Another situation from the food radiation is water radiolysis, or water broken by the ionizing radiation that forms analytes as H^+ and OH^- . From the water radiolysis, the formation of hydrogen peroxide has great significance in irradiated foods. Like all foods containing substances that can oxidize or reduce, many reactions can occur when foods containing water are irradiated [11].

3.2. Consumer acceptance and marketing of irradiated foods

Although irradiation cannot prevent primary contamination, it is the most effective tool available to significantly reduce or eliminate harmful bacteria in raw product. Food irradiation has the virtual to dramatically reduce the incidence of foodborne illness and has gained practically consentaneous aid or approbation from international and national medical, scientific, and public welfare organizations, also from food processors and associated industry groups. Numerous consumer studies clearly show that when given a choice and even a small amount

of accurate information, consumers are not only willing to buy irradiated foods but also often prefer them over food treated by conventional means [13].

4. Food intolerance and allergies

Primary food sensitivities can be cloven into immunological and nonimmunological responses. The base of an unnatural immunological reaction after expenditure is a real food allergy or hypersensitivity. Primary sensitivities involving immunological retroactions are more piecemeal into IgE-mediated and non-IgE-mediated food allergies. The reactions are often noted as immediate hypersensitivity reactions, because the symptoms occur soon after ingesting the offending foods. Food allergens are defined as common food proteins (foods contain many proteins, but only a few of them are allergens). As in all people, the allergens are ingested, pass through the gut epithelium, and circulate in the blood; however, the immune system of some individuals reacts to these food allergens by manufacturing immunoglobulin E (IgE) [20].

5. Chemical and biological properties of food allergens

For Jedrychowski and Wichers [21], most of the allergens have a protein; they are usually glycoproteins dissolved in water and resistant to digestion. The immune system recognizes them, and as a result, specific IgEs are produced (type I allergy) or specific T-cell antigen receptors (TCRs) are produced (type IV allergy).

Harder et al. [11] treated the debate on the effect of radiation in proteins formed on the study of the radiation chemistry of amino acids. Started responses with hydrated electrons are the main route in the radiolysis of amino acids and proteins. When proteins are irradiated in the attendance of water, all of the retroactions that are possible with amino acids are also practicable with proteins holding these amino acids. With 20 component amino acids and proteins with three reactive kinds of water radiolysis, many complicated interactions are practical. Further, the effects are exercised by the spatial shape of the protein current, determined by hydrogen links, disulfide links, hydrophobic links, and ionic links. Lonely, amino acids, which are likely to attack by radicals when irradiated, are less susceptible when they are part of the protein structure and they are more or less inaccessible to responses with radicals. Another factor that probably contributes to the increased force compared with the protein-isolated amino acid sequence is owing to a greater or lesser hardness of the spatial structure of the protein; radicals created as a result of irradiation molecule are safe in the stance and have a high chance of recombination.

The authors also said that a great proportion of radiant energy laid up in irradiated proteins seemingly promotes denaturation, and modifies in secondary and tertiary current, before the destruction of the amino acid components. This denaturation is much less longer than that caused by warmth. This is because sterilizing radiation in food for much time housing combines with warm treatment. Enzymes are more sensible to warmth.

6. Application of gamma irradiation for inhibition of food allergy

According to Byun et al. [16], the amount of intact allergens in an irradiated solution can be reduced by gamma irradiation depending upon the dose. This situation occurs because that in the epitopes on the allergens can be structurally altered by radiation treatment and that the irradiation technology can be applied to reduce allergenicity of allergic foods.

Kume et al. [6] observed the structural modification of food proteins by radiation, and these results have indicated that ionizing radiation could change antigenicity by the destruction or modification of antibody-binding epitopes in food antigens/allergens.

7. Effect of irradiation on allergenicity of different food products

Food irradiation objective is the inactivation of microorganisms and through this to prolong the shelf-life. As side effect, this technology influences the food allergenicity.

The process of irradiating proteins with high dose besides inactivation of microorganisms induced the production of protein aggregates and degraded fragments with reactivity to the specific antibodies.

One example is the research that Vaz et al. [22] conducted. Studies on *Sebastiania jacobinensis* bark lectin found that high doses of gamma irradiation (above 1 kGy) induced a significant loss of activity of this protein. There were apparent changes in the hydrophobic surface. Gamma irradiation caused protein misfolding and aggregation.

After these reports, other research developed within the effect of irradiation on allergenicity of different food products thematic has been subsequently listed.

8. Eggs

For egg proteins, Lee et al. (2005) produced cakes containing layer of egg white that were gamma-irradiated with 10 or 20kGy in study promoted by them. The ovalbumin present decreased its allergenicity by irradiation and processing. Egg white irradiated for reducing the egg allergy could be used for producing a safer cake [23]. And then, Lee et al. [24] treated hen egg ovomucoid at basic pH irradiated at 10 kGy, heated at 100°C for 15 min, or both treatments were applied. The combination of irradiation and heating was very effective in reducing the amount of intact ovomucoid regardless of the pH condition. For Kume and Matsuda [7], the principle of the effect can be demonstrated in case of ovalbumin and bovine serum albumin in solution (0.2% in 0.01 M phosphate buffer, pH 7.4). These proteins were irradiated with a high dose of the order of 8 kGy (units for intensity characterization of ionization by gamma irradiation). This process besides inactivation of microorganisms induced the production of protein aggregates and degraded fragments with reactivity to the specific antibodies. The main part of conformation-dependent reactivity, spatial antigenic structure (conformational epitope), was lost, but some antigenicity persisted.

In their study, Kim et al. [25] was carried out to evaluate the changes in the allergenic and antigenic properties of hen's egg albumin (ovalbumin) with the combination of heat and gamma irradiation treatment. They found that the ovalbumin's capacity to connect to mouse IgG modified upon heating at 167°F and its capacity to connect to egg-allergic IgE modified upon heating at 176°F. The ELISAs introduced that egg-allergic IgE did not identify ovalbumin very well when warmish at $\geq 176^\circ\text{F}$, while mouse IgG maintained better activity under these requirements specimen treated by irradiation followed by warming. For that, these consequences demonstrate that allergies induced by ovalbumin could be effectively decreased by the blend of warm and gamma irradiation treatment.

Lee et al. [24] in their study evaluated the effect of a treatment combining gamma radiation and heating on the allergenic properties of hen's egg ovomucoid under basic pH conditions. They observed that the concentration of unimpaired ovomucoid reduced with irradiation or warming, and the fee of the reduction was larger for a basic pH requirement than for the physiological requirement. Ultimately, they concluded that the blend of irradiation and heating was very effective in reducing the amount of intact ovomucoid regardless of the pH condition. After treatment, the renovation of the pH to 7.4 did not affect the concentration of ovomucoid. The results of this study indicate that a combination of irradiation and warming might be an effective way for decreasing egg hypersensitivity resulting from ovomucoid.

9. Milk

Milk proteins allergen was studied by Lee et al. [26] who found that bovine alpha-casein and beta-lactoglobulin when irradiated changed their allergenicity and antigenicity. Probably, agglomeration of proteins was caused by the treatment.

In their study, Lee et al. [26] executed to assess the application of food irradiation technology as a way for decreasing milk allergies. In this scientific study, bovine alpha-casein and beta-lactoglobulin were used as milk proteins. The application of milk-hypersensitive patients' immunoglobulin E and rabbit IgGs individually made to bovine alpha-casein and beta-lactoglobulin, the shift of allergenicity and antigenicity of irradiated proteins was noted by competitive oblique enzyme-linked immunosorbent test.

For the authors, allergenicity and antigenicity of the irradiated proteins were modified unlike sides of the inhibition curves. The vanishing of the band on sodium dodecyl sulfate-polyacrylamide gel electrophoresis and the rise of the turbidity demonstrated that solubility of the proteins decreased by radiation, and it might be caused by agglomeration of the proteins. These results showed that epitopes on milk allergens were structurally changed by gamma irradiation.

10. Fish and seafood

Our research evaluated heat-stable protein that was secluded and processed with gamma radiation at 0, 1, 3, 5, 7, and 10 kGy in a requirement of solution (1 mg/ml) and fresh shrimp

was irradiated too. The IgE-linking fee was decreased with an increasing dose. The principal allergenic protein was gone and the vestiges induced from coagulation showed up at a higher molecular weight zone as evidenced by a special test. The same results were received on proteins extracted from irradiated shrimp studied by Byun et al. [27].

Investigations on glutamic oxaloacetic transaminase, glutamic pyruvate transaminase, and rhodanese of both unirradiated and irradiated chub mackerel (*Rastrelliger neglectus*) have been carried out by Sofyan and Soedigdo [28]. They can be proved that glutamic oxaloacetic transaminase and glutamic pyruvate transaminase were more susceptible toward irradiation as compared to rhodanese. An irradiation dose of 4 kGy was able to inactivate glutamic oxaloacetic transaminase, glutamic pyruvate transaminase, and rhodanese for ca 50, 44, and 36%, respectively. Evidently, transaminase- as well as rhodanese-specific activities to spoiled fish were significantly lower ($P \leq 0.01$) than those of fresh fish. The residual glutamic oxaloacetic transaminase-, glutamic pyruvate transaminase-, and rhodanese-specific activities in spoiled fish were found to be about 35, 41, and 22%, respectively.

11. Wheat

Commercial gliadin powder and wheat flour were irradiated with doses between 2.2 and 12.8 kGy. Surprisingly, irradiated gliadin increased its allergenicity. Gliadin extracted from irradiated wheat flour exhibited higher immunoreactivity than pure gliadin irradiated with the same dose [29].

12. Conclusion

Regarding earlier explanation, we can conclude that the ionizing radiation is effective to control the allergenicity in food. But more studies are necessary to determine the chronic and acute doses, as well as the dose rate, pH, temperature, humidity, and other parameters that can influence the food characteristics.

Author details

Marcia Nalesso Costa Harder^{1*}, Valter Arthur² and Larissa Nalesso Costa Harder³

*Address all correspondence to: marcia.harder@fatec.sp.gov.br

1 Technology College of Piracicaba “Dep. Roque Trevisan,” Piracicaba, São Paulo, Brazil

2 Nuclear Energy Center in Agriculture—CENA/USP, Piracicaba, São Paulo, Brazil

3 State University Northern of Parana, Jacarezinho, Paraná, Brazil

References

- [1] Mastro NL. Ionizing radiation for the promotion of adequate and healthy food. *Vigilância Sanitária em Debate*. 2015;**3**(2):114-121
- [2] Prejean JE. Food Irradiation [Internet]. 2001. Available from: <https://dash.harvard.edu/bitstream/handle/1/8846796/Prejeanpap.html?sequence=3> [Accessed: February 2017]
- [3] EAACI. Definições em alergia [Internet]. 2017 [Updated: 2017]. Available from: http://www.eaaci.org/attachments/977_portuguese.htm [Accessed: February 2017]
- [4] Nilsson C, Oman H, Harfast B. A case of allergy to cow's milk hydrolysate. *Allergy*. 1999;**54**:1322-1325
- [5] Melo Vaz AF. Estabilidade estrutural e funcional de lectinas submetidas à irradiação gama: Potencial em alergia alimentar [thesis]. UFPE: UFPE; 2011. p. 141
- [6] Kume T, Ishii T, Matsuda T. Immunochemical identification of irradiated chicken eggs. *Journal of Science and Food Agriculture*. 1994;**65**:1-4
- [7] Kume T, Matsuda T. Changes in structural and antigenic properties of proteins by radiation. *Radiation Physics and Chemistry*. 1995;**46**:225-231
- [8] Lee JW, Yook HS, Lee KH, Kim JH, Byun MW. Conformational changes of myosin by gamma irradiation. *Radiation Physics and Chemistry*. 2000;**58**:271-277
- [9] Harder MNC, Arthur V. Effects of gamma radiation for microbiological control in eggs. In: Hester P, editor. *Egg Innovation and Strategies for Improvement*. 1st ed. Oxford: Elsevier Inc.; 2017. pp. 177-186
- [10] Center for Disease Control (CDC). Frequently Asked Questions about Food Irradiation [Internet]. 1999 [Updated: 1999]. Available from: <http://www.cdc.gov/ncidod/dbmd/diseaseinfo/foorirradiation.htm> [Accessed: February 2017]
- [11] Harder MNC, Arthur V, Arthur PB. Effect of ionizing radiation on food components. In: Caballero B, Finglas P, Toldrá F, editors. *The Encyclopedia of Food and Health*. 3rd ed. Oxford: Elsevier Inc.; 2016. pp. 476-481
- [12] Morehouse KM. Food irradiation: The treatment of foods with ionizing radiation. *Food Testing and Analysis*. 1998;**8**(3):9-35
- [13] Eustice RF, Bruhn CM. Consumer acceptance and marketing. In: Fan X, Sommers CH, editors. *Food Irradiation Research and Technology*. 2nd ed. Oxford: Blackwell Publishing; 2013. pp. 173-193
- [14] World Health Organization. Food Safety and Nutritional Adequacy of Irradiated Foods. 1st ed. Geneva: WHO; 1994. p. 182
- [15] Satin M. Radiation of Food. 1st ed. Zaragoza: Editorial Acribia; 1997. p. 221

- [16] Byun MW, Lee JW, Yook HS, Jo C, Kim HY. Application of gamma irradiation for inhibition of food allergy. *Radiation Physics and Chemistry*. 2002;**63**:369-370
- [17] Harder MNC. Effect of gamma radiation on allergenic protein hen eggs [thesis]. Piracicaba: USP; 2009. p. 62
- [18] US Food and Drug Administration. Irradiation: A Safe Measure for Safer Iceberg Lettuce and Spinach [Internet]. 2008 [Updated: 2008]. Available from: <http://www.fda.gov/downloads/ForConsumers/ConsumerUpdates/UCM143389.pdf> [Accessed: February 2017]
- [19] Food and Drug Administration. Irradiation in the Production, Processing and Handling of Food [Internet]. 2012 [Updated: 2012]. Available from: <https://www.federalregister.gov/documents/2012/11/30/2012-28967/irradiation-in-the-production-processing-and-handling-of-food> [Accessed: February 2017]
- [20] Bernard H. Food Irradiation [Internet]. 2017 [Updated: 2017]. Available from: <http://www.barnardhealth.us/food-irradiation/food-intolerance-and-allergy.html> 2017 [Accessed: February 2017]
- [21] Jedrychowski L, Wichers HJ. Chemical and Biological Properties for Food Allergens. 1st ed. CRC Press, Boca Raton; 2009. p. 447
- [22] Vaz AFM, Costa RMPB, Coelho LCBB, Oliva MLV, Santana LA, Melo AMMA, Correia MTS. Gamma irradiation as an alternative treatment to abolish allergenicity of lectins in food. *Food Chemistry*. 2011;**124**(4):1289-1295
- [23] Lee JW, Seo JH, Kim JH, Lee SY, Kim KS, Byun MW. Changes of the antigenic and allergenic properties of a hen's egg albumin in a cake with gamma-irradiated egg white. *Radiation Physics and Chemistry*. 2005;**72**:645-650
- [24] Lee JW, Lee KY, Yook HS, Lee SY, Kim HY, Jo C, Byun MW. Allergenicity of hen's egg ovomucoid gamma irradiated and heated under different pH conditions. *Journal of Food Protection*. 2002;**65**:1196-1199
- [25] Kim MJ, Lee JW, Yook HS, Lee SY, Kim MC, Byun MW. Changes in the antigenic and immunoglobulin E-binding properties of hen's egg albumin with the combination of heat and gamma irradiation treatment. *Journal of Food Protection*. 2002;**65**(7):1192-1195
- [26] Lee JW, Kim JH, Yook HS, Kang KO, Lee SY, Hwang HJ, Byun MW. Effects of gamma radiation on the allergenic and antigenic properties of milk proteins. *Journal of Food Protection*. 2001;**64**:272-276
- [27] Byun MW, Kim JH, Lee JW, Park JW, Hong CS, Kang IJ. Effects of gamma radiation on the conformational and antigenic properties of a heat-stable major allergen in brown shrimp. *Journal of Food Protection*. 2000;**63**:940-944
- [28] Sofyan R, Soedigdo S. The effect of gamma irradiation on fish transaminase and rhodanese. *Journal of the Indonesian Atomic Energy Agency*. 1983;**16**(1):75-82
- [29] Leszczynska J, Lacka A, Szmaj J, Lukamowicz J, Zegota H. The influence of gamma irradiation on the immunoreactivity of gliadin and wheat flour. *European Food Research and Technology*. 2003;**217**:143-147