Irradiation Applications in Food Products

Ozlem EROL

Nigde Omer Halisdemir University, Faculty of Agricultural Sciences and Technologies, Department of Animal Production and Technologies, Nigde, Turkiye

Corresponding author: ozlemerol001@gmail.com

ORCID: 0009-0005-7416-765X

Abstract

To prevent hunger and malnutrition in the world, increasing food production alone is not enough. However, food safety and quality must also be ensured in the preservation of the produced food. For this purpose, in addition to the use of traditional methods, innovative methods such as irradiation have been developed and put into practice. Food irradiation is a technology used to reduce pathogens and food-borne diseases by giving a certain amount of energy to packaged or bulk foods, and to improve food safety by inactivating microorganisms that may cause food spoilage. Today, approximately 200 types of foods are irradiated in many countries using irradiation technology. Some of these foods are fruits and vegetables, meat and meat products, eggs, spices and aromatic plants, nuts and oilseeds. This article aims to provide information about irradiation, to mention irradiation applications in some foods (irradiation of fruits and vegetables, meat and meat products and spices), and to mention consumers' perspectives on irradiated food.

Keywords: Food Irradiation, Food Safety, Food Processing

Review article
Received Date: 23 November 2024
Accepted Date: 23 December 2024

INTRODUCTION

Hunger and malnutrition are among the most important problems encountered in the world (UN News, 2017). In order to overcome the hunger problem, it is not enough to increase food production alone, in addition to this, preservation methods should be applied in the quality and reliability of food. It is very difficult to transport and protect products without any loss in the products during food preservation. For this reason, innovative methods are also used in addition to traditional methods (Halkman et al., 2010).

The history of food irradiation dates back to the discovery of X-rays by Roentgen in 1895 and the discovery of radioactivity by Becquerel in 1896 (Diehl, 2002). Currently, irradiation is applied to one or more foods in more than 60 countries in the world; among these countries, China, the USA and Ukraine have the largest share of irradiated foods, and China is one of the leading countries in its trade. Two gamma irradiation facilities have been established in Turkey, the first of which was established in Sarayköy/Ankara in 1992 and the second in Çerkezköy/Tekirdağ, the first private sector commercial facility established in 1995 (Sarıbay, 2017).

Food irradiation technology is the application used to improve food safety with a certain energy, namely ionized energy, in packaged or bulk foods (Arvanitoyannis, 2011; Sarıbay, 2017). In this context, 3 types of irradiations are used in food preservation: gamma rays, X-rays and accelerated electron beams (Olson, 1998; Ceylan and Özoğul, 2020). Among these, gamma rays are the most frequently used in industry (WHO, 1994). According to the Food and Agriculture Organization (FAO), World Health Organization (WHO), Codex Commission (CAC) and International Atomic Energy Agency (IAEA), which have worked together on the quality and safety of many irradiated foods, it has been concluded that the application of irradiation technology with one or more methods is a technology that extends the shelf life of foods and also provides microbial safety (IAEA, 2009). Every product using irradiation technology must have the 'radura' symbol on its packaging to inform the consumer (Figure 1). This article includes a diversity of the history of technology, its assessment and applications in various food groups, and consumer perception.

Figure 1. Radura symbol

PURPOSES, ADVANTAGES and DISADVANTAGES of FOOD IRRADIATION

Food irradiation is not only used to reduce disease-causing microorganisms (pathogens) and foodborne illnesses, to eliminate microorganisms that will cause spoilage, to minimize food spoilage, but it can also be used in foodstuffs to reduce product losses during sprouting, germination and ripening, and to reduce the contact of organisms that are harmful to plants or plant-derived products with foodstuffs (Halkman et al., 2010).

Food irradiation has both positive and negative aspects. Its benefits are that food products remain more natural due to not being exposed to heat, that it has a comprehensive effect on microorganisms and insects that cause food-based harvests, that it can be applied to packaging and therefore protects people from epidemics caused by food, and that it also has a positive effect on the rate of food-borne diseases as a result of studies (Hoefer et al., 2006; Nayga et al., 2004). In addition to this, it does not leave any chemical traces in food products and reduces the use of chemical substances in many food sectors (WHO, 2005). It is also used to prevent pests in some tropical or semi-tropical vegetables and fruits from spreading to different regions with export. It slows down ripening and rotting in foods, ensures that the product maintains its freshness for a longer period, and as a result, the shelf life of the product is extended.

In terms of the negative aspects that need to be improved, the consumer's perspective on irradiated food is one of the obstacles to the widespread use of this technology. However, some studies have yielded some unpleasant results in the physical properties of foods (taste, smell and texture). At the same time, radiolytic products can be released by irradiation. The most important radiolytic product of these is 2-alkylcyclobutanone. This is determined by the standards published by the European Standardization Board in the determination of irradiated foods (EN, 1785).

IRRADIATION APPLICATIONS in FOODS

The essence of the successful implementation of irradiation in food products is based on the inhibition of DNA synthesis during cell division. Inactivation of microorganisms by irradiation is the result of DNA damage (Halkman and Kozat 2005; Anonymous, 2005; Dickson, 2001; Farkas, 1997).

Although irradiation is an effective method used to preserve fresh and perishable foods because it is a physical process that leaves no chemical residue (traces), it is not possible to use it on every food (Lagunas-Solar, 1995). For example, rancidity in fatty food products and bad odor and taste formation in high-protein food products narrow down the area of use of irradiation. Currently, approximately 200 types of foods are irradiated using irradiation technology in many countries. (Farkas and Mohacsi-Farkas, 2011; Cleland and Stichelbaut, 2013; Mitchell, 1994; Lee et al., 2004). Some of the foods subjected to irradiation are fruits and vegetables, meat and meat products, eggs, spices and aromatic herbs, nuts and oilseeds (Yılmaz and Ülger, 2016; Olson, 1998); the irradiation of fruits and vegetables, meat and meat products and finally spices are explained below.

Irradıatıon of Fruıts and Vegetables

Losses occur in products due to different reasons in the stages from production of fruits and vegetables to reaching the consumer. Although various techniques such as early harvesting, chemical use, storage in cold atmosphere and packaging are used in production in order to reduce these losses, the effect of water and microbial activities on fruits and vegetables on losses is high. For this reason, in addition to food preservation methods, the use of irradiation methods is also important in minimizing losses (Dinçer and Topuz, 2006). As a result of irradiation, sprouting of fresh fruits and vegetables is prevented, ripening is controlled, insects and pests are inactivated and finally mold, yeast and bacteria are inhibited (Farkas, 2006). Chemical applications are mostly used to ensure the microbial safety of fresh fruits and vegetables, and the chemical traces left by these in foods are a major negativity in their use. Microbial safety can be achieved without leaving any chemical traces in fresh vegetables and fruits by irradiation (Başbayraktar and Güçlü, 2009).

Many studies have been conducted to extend the shelf life of fresh fruits and vegetables. (Farkas, 1990; Lacroix et al., 1991). A study conducted by the Canadian Irradiation Center on citrus fruits showed that washing with warm water and waxing processes to extend the shelf life of foods caused losses in fruits during storage, and it was stated that there was a loss of less than 11% in tangerines irradiated with 0.3 kGy and stored at 3°C after 8 weeks (Abdellaoui et al., 1995).

In a study where low doses (0.25-1 kGy) of γ-rays were applied to packaged Basmati rice to prevent infestation, extreme infestation was detected in unirradiated rice after 30 days of storage at room temperature, while it was not detected in irradiated rice even at a dose of 0.25 kGy (Sudha Rao et al., 2000).

In a study for the inactivation of Hepatitis A virus (HAV), gamma irradiation doses ranging from 1 to 10 kGy were applied to inoculate green lettuce and strawberries at room temperature, and as a result of data analysis with the linear model, it was determined that gamma irradiation doses between 2.7 and 3 kGy were required to achieve a 90% reduction in the HAV population in fruits and vegetables (Bidawid et al., 2000).

In the study conducted to determine the effect of irradiation technology on the quality of lightly processed carrots, carrots were peeled, sliced and packed in polyethylene packaging material. Following irradiation and during two weeks of storage, no coliform or E. coli was detected in any sample (irradiated or control). As a result, irradiation at 2 kGy completely reduced the number of fungi and bacteria (Chaudry et al., 2004).

As a result of the investigation of Listeria monocytogenes inactivation in broccoli, cabbage, tomato and mung bean seeds inoculated in the laboratory; it was determined that irradiation at 1 kGy caused a decrease of 4.88 log cfu/g in broccoli seeds and 4.57 log cfu/g in bean seeds, and these rates caused a decrease of approximately 5.25 log cfu/g in cabbage and 4.14 log cfu/g in tomatoes irradiated at similar doses. As a result, it was stated that irradiation applied at low doses could be an effective method for the inactivation of L. monocytogenes in fresh and fresh-cut products (Bari et al., 2005).

It is known that the use of irradiation technology in fresh fruits and vegetables not only neutralizes microorganisms that cause spoilage, but also has a positive effect on the shelf life of the product. Although many different fruits and vegetables are tolerant of low-dose applications, the biggest obstacle to the use of food irradiation in fruits and vegetables is the softening that occurs in the products (Fan et al., 2003a; Fan et al., 2003b). "Low" irradiation doses of up to 1 kGy are indicated as suitable for controlling insects in cereals, preventing sprouting in white potatoes and preventing rotting in fruit and vegetables (Webb and Penner, 2000).

Irradiation of Meat and Meat Products

Meats are very sensitive to oxidative deterioration caused by the oxidation of polyunsaturated fatty acids in their structure (Giroux and Lacroix, 1998). With irradiation, the abundant water in meat is ionized and free radicals are formed. These free radicals cause lipid and protein deterioration, which creates an undesirable taste in meats (Merritt et al., 1978; Giroux and Lacroix, 1998). Since polyunsaturated fatty acids are oxidized rapidly, precautions must be taken during irradiation (Merritt et al., 1978). Today, in poultry meat, the only physical method that can make contaminated poultry safe, in addition to heat treatment, is irradiation. 11 countries have recognized the value of irradiation technology in the safety of poultry products and have approved the use of irradiation in this area (Molins et al., 2001).

It has been determined that doses lower than 10 kGy are used to control the growth of pathogenic and spoilage bacteria (*L. monocytogenes, S. typhimurium, E. coli* O157:H7 and *Y. enterocolitica*) in meat and meat products (Thayer and Boyd, 2001; Mermelstein, 2000; Monk et al., 1995). It has been determined that most enteric pathogens (*Campylobacter jejuni, Escherichia coli O157:H7, Staphylococcus aureus, Salmonella spp., Listeria monocytogenes and Aeromonas hydrophila*) can be significantly reduced or inactivated with low-dose (< 3 kGy) irradiation applications in poultry meat. Only enteric viruses and endospores of the Clostridium and Bacillus genera show serious resistance to irradiation, and these are affected to some extent (Thayer, 1995). Low doses of irradiation play an active role in inactivating Salmonella species as well as keeping food fresh for a long time. In a study conducted in this context, irradiation of fresh chicken carcasses, parts or boned chicken meat at 2.5 kGy is generally appropriate in preventing inactivation with natural Salmonella found at very low levels (1 to 30 cells/100 g). In frozen chicken, doses higher than 2.5 kGy are needed to ensure inactivation of Salmonella spp. (Singh, 1992). There are studies that conclude that the irradiation applications recommended for inactivating *Salmonella spp*. and *Listeria monocytogenes* from poultry carcasses are also sufficient for Campylobacter species (Patterson, 1995).

Although irradiation is a method that has been used successfully to reduce the number of *E. coli O157:H7* in red meat and poultry, radiation sensitivity depends on different factors. After 1 kGy irradiation, a decrease of 3-4 logarithmic units was found in the initial number of *E. coli.* D10 = 0.27 kGy was determined in meat medium and D10 = 0.47 kGy in turkey meat (Mayer, 1993).

Various studies have determined that *E. coli O157:H7* is not resistant to irradiation and that irradiation will provide significant hygiene protection in food products, especially meat products (Halkman et al., 2001).

In a study evaluating the sensory properties (flavor and liking) of meatballs prepared from beef and irradiated at a dose of 1.5 kGy, these properties were examined, and it was concluded that there was no difference in total liking, hardness, flavor and textural liking between irradiated and non-irradiated samples, only irradiated meatballs were juicier and had a redder color (Vickers and Wang, 2002).

Fresh fish have a short shelf life because they are sensitive to microorganisms that may cause spoilage in their structure (ICGFI, 1998). Gram-negative bacteria, which are the main cause of spoilage in marine and freshwater fish, are more sensitive to irradiation applications than Gram-positive bacteria. In other words, by applying low irradiation doses such as 1-3 kGy, the initial load of microorganisms that may cause possible spoilage can be reduced by 1-3 logarithm units, thus increasing the storage period of fresh fish. The dose level to be used in irradiation to increase the storage period is determined according to the amount that will not endanger health for each species and to have sensory properties acceptable to the buyer (Grodner and Andrews, 1991). Food irradiation can change the quality of meat products as well as their color, lipid oxidation and microbial properties (Ham et al., 2017). Excessive dose application during the irradiation process can cause undesirable changes, especially in meat products, due to increased lipid peroxidation in foods and negatively affecting the shelf life of foods (Kima et al., 2002; Lung et al., 2015).

Spice Irradiation

Spices, which are frequently used in the world, are contaminated with bacteria, yeasts and molds when they encounter unhygienic conditions during harvest, growing conditions and various stages such as drying, and their microbial loads also increase (Sagoo et al., 2009; Roberts, 2016). While the low water content and ratio of spices cause their microbiological activity to be low, they can cause microbiological contamination when they are together with foods with high water content and activity (Schweiggert et al., 2007).

Spices and aromatic plants are sterilized with steam, ethylene oxide or irradiation before they reach humans. Their use is limited due to the losses in volatile fatty acids in steam sterilization and the toxic effects of ethylene oxide sterilization. Gamma irradiation is a method that is successfully applied in spices because it does not change the aroma quality and prevents microbial contamination (Farkas, 1988). In the last five years, the irradiation of spices and condiments has increased, from 2.5% to 22.5%. According to January 2000 data, 95 million pounds of the total 97 million pounds of food irradiated annually in the USA were determined to be spices (Abbas, 2002; Piggott and Othman,1993).

It is the most common application used to ensure the hygiene and health conditions of spices; international organizations and institutions such as FDA and WHO also approve irradiation of spices (FDA, 2016).

It is mentioned that irradiation application in spices is a very effective and reliable type of sterilization because it causes a significant decrease in the number of bacteria (Hayashi et al., 1994; Szabad and Kiss, 1979; Sirnik and Jamsek, 1981). For example, it has been determined that 10 kGy dose of irradiation in pre-packaged spices with a high microorganism load eliminates microorganisms without any loss of quality, and that 5 kGy dose is sufficient to eliminate molds (Abbas, 2002).

CONSUMER and IRRADIATED FOOD

In order for an application to be commercially implemented, it must be adopted by the consumer. Consumers' approach to irradiation technologies and the products they are applied to is mostly negative due to fear, incorrect and insufficient information about the application. In a study conducted in the USA, it was determined that 82% of consumers were unaware of irradiation application, while 72% were aware. In the study, 30% of consumers were of the opinion that foods were radioactive (Resurrection, et al., 1995).

It has been determined that information and educational activities about irradiation carried out by researchers are effective in consumers' perspectives on food (Fox, 2002; (Oliveira and Sebato, 2002). Consumers' perspectives on food safety vary depending on cultural and demographic factors such as gender, age, marital status, income and education level, country's level of development, etc. (Wilcock et al., 2004).

In a study of consumer attitudes toward food irradiation in São Paulo, Brazil, three focus groups were conducted with 30 consumers. Participants were served both irradiated and non-irradiated food samples during the sessions and their reactions were observed. The results were similar between the groups, with almost no perceptible differences between the irradiated and non-irradiated samples.

When consumers were provided with information about the benefits of irradiation to food and human health, many people remained skeptical about the safety of technology (Behrens et al., 2009). In another study, a consumer panel of 50 people was recruited to evaluate the sensory properties and consumer acceptance of electron beam irradiated ready-to-eat meats. The acceptability of irradiated foods was higher than that of non-irradiated ones. Approximately 76% preferred to purchase irradiated pork and 68% preferred to purchase irradiated poultry to minimize the possibility of contracting Trichinella and Salmonellae, respectively (Johnson et al. 2004).

As a result of the joint studies conducted by FAO, IAEA, WHO and CAC on the quality and safety of food using various irradiation applications, it has been determined that irradiation technology, whether used alone or in addition to another method, is a technology that provides microbial safety in food and is used in food preservation (IAEA, 2009).

CONCLUSION

Food irradiation is a technology that has found application in different sectors of food due to its many advantages and has developed over time. Although irradiation applications vary depending on the type of products to be irradiated, studies on it are still ongoing today.

In recent years, with the understanding of the value of irradiation, consumer awareness efforts have begun to increase. In this context, more studies are needed on the subject, and awareness of food irradiation should be created by supporting the studies by various institutions and organizations and presenting them to consumers.

REFERENCES

Abbas S.M.N. 2002. Baharat Mikroflorası Üzerine Işınlamanın Etkisi. Ankara Üniversitesi Fen Bilimleri Enstitüsü Gıda Mühendisliği AbD, *Doktora Tezi*, 81s. Ankara.

Abdellaoui S., Lacroix M., Jobin M., Boubekri C. & Gagnon M. 1995. Effect Of Gamma Irradition Combined with Hot Water Treatment on The Physico-Chemical, Nutritional and Organoleptic Qualities of Clementines. *Int. J. Food Sci. Technol.*, 15, 217 235.

Alkan H. 2003. Industrial Gamma Irradiation Applications in Turkey. *Gamma-Pak Sterilizasyon A.Ş.*, İstanbul http://simad55.tripod.com/kitap2003/19.htm

Anonymous 2005. Facts about Food İrradiation. http://www.iaea.org/programmes/nafa/d5/public/foodirradiation.pdf.

Arvanitoyannis I.S. 2011. Irradiation of Food Commodities, Techiniques, Apparataus, Dedection, Legislation, Safety and Consumer Opinion, *Elsevier*, First edition, Oxford, UK. pp. 710.

Bari M.L., Nakauma M., Todoriki S., Juneja V.K., Isshiki K. & Kawamoto S. 2005. Effectiveness of Irradiation Treatments in Inactivating *Listeria monocytogenes* on Fresh Vegetables at Refrigeration Temperature, *J. Food Prot.*, Feb, 68(2), 318-323.

Başbayraktar V. & Güçlü H. 2009. Effect of Irradiation on the Quality of Fresh Fruits and Vegetables. 2009; X. *National Congress of Nuclear Sciences and Technologies*, 284-289, Muğla.

Behrens J. H., Barcellos M.N., Frewer L.J., Nunes T.P. & Landgraf M. 2009. Brazilian Consumer Views on Food İrradiation, *Innovative Food Science & Emerging Technologies,* 383-389.

Bidawid S., Farber J. M. & Sattarb S. A. 2000. Inactivation of Hepatitis A Virus (HAV) in Fruits and Vegetables by Gamma Irradiation, *Int. J. Food Microbiol.,* 57, 91–97.

Bruhn C. M. 1998. Consumer Acceptance of Irradiated Food: Theory And Reality. *Radiation Physics and Chemistry,* 52, 129–133.

Cain R. F., Anglemier A. F., Sather L. A., Bautista F. R. & Thompson R. H. 1958. Acception Of Fresh and Precooked Radiated Meats. *Food Research*, 23, 603-610.

Ceylan Z. & Özoğul Y. 2020. Irradiation Technology. *Innovative Technologies in Seafood Processing.*Y. Özoğul (ed.), pp.115-129.

Chaudry M. A., Ashraf M., Bibi N., Khan M., Khan M., Badshah A. & Qureshi M. J., 2004. Irradiation Treatment of Minimally Processed Carrots for Ensuring Microbiological Safety, *Radiation Physics and Chemistry*. 1,169–173.

Cleland M.R. & Stichelbaut F. 2013. Radiation Processing with High-Energy Xrays. *Radiation Physics and Chemistry*. 84, 91-99.

Dickson J. 2001. Radiation Inactivation of Microorganisms. *In: Food Irradiation Principles and Applications*. Sayfa: 23-32, John Wiley&Sons, New York, USA, 469s.

Diehl J.F. 2002. Food Irradiation-Past, Present and Future, *Radiation Physics and Chemistry*. 63, 211–215.

Dinçer C. & Topuz A. 2006. Use of Ionizing Radiation in Preserving Fruits and Vegetables. *9th Turkish Food Congress*, Bolu.

Ehlermann D. A. E. 2009. The RADURA Terminology and Food Irradiation. *Food Control* 20(5), 526-528.

Ehlermann D. A. E. 2016. Particular Applications of Food Irradiation: Meat, Fish and Others. *Radiation Physics and Chemistry*. 129, 53–57.

Ehlermann D. A. E. 2016. The Early History of Food Irradiation. Radiation Physics and Chemistry. (129), 10-12

European Commission (EC). 2004. Commission Decision of 7 October 2004 Amending Decision 2002/840/EC Adopting the List of Approved Facilities in Third Countries for the Irradiation of Foods. *Official J. of European Commission*

Fan X., Niemira B.A. & Sokorai K.J.B. 2003a. Sensorial, Nutritional and Microbiological Quality of Fresh Cilantro Leaves as Influenced by Ionizing Irradiation and Storage. *Food Res. Int.* 36(7), 713-719.

Fan X., Toivonen P.M.A., Rajkowski K.T. & Sokorai K.J.B. 2003b. Warm Water Treatment in Combination with Modified Atmosphere Packaging Reduced Undesirable Effects Or Irradiation On The Quality Of Freshcut Iceberg Lettuce. *J. Agric. Food Chem*. 50, 1231-1236.

Farkas J. & Mohacsi-Farkas C. 2011. History and Future of Food Irradiation. *Trends Food Sci. Technol*. 22, 121-126.

Farkas J. 2006 Irradiation for Better Foods. *Trends Food Sci. Technol.* 17(4), 148-152

Farkas J. & Mohácsi-Farkas C. 2011. History and Future of Food Irradiation. *Trends in Food Science & Technology* 22(2-3), 121-126.

Farkas J. 1988. Irradiation Of Dry Food Ingredients. *CRC Press*, FL, 1-9, 25-36.

Farkas J. 1990. Combination Of Irradiation with Mild Heat Treatment. *Food Control*, 1, 223-229.

Farkas J. 1997. Physical Methods of Food Preservation. Michael P. Doyle, Larry R. Beuchat & Thomas J. Montville (Ed.). Food Microbiology Fundamentals and Frontiers. pp.497-519. *ASM Press Washington* D.C. p.768

FDA U.S. Food & Drug Administration 1986. https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfCFR/CFRSearch.cfm?fr=1 79.26, (Accesible: 10.05.2019).

Food and Drug Administration (FDA). Food Facts. www.fda.gov/educationresourcelibrary. (Accessible: 16.09.2016).

Johnson A.M., Reynolds A.E., Chen J. & Resurreccion A.V.A. 2004. Food Processing Preservation 28, 302

Fox J. A. 2002. Influences On Purchase of Irradiated Foods. *Food Technology*, 56, 1–8.

Giroux M. & Lacroix M. 1998. Nutritional Adequacy of Irradiated Meat: A Review. *Food Research Int*., 31, 257-264.

Grodner R. M. & Andrews L. S. 1991. Irradiation. In 'Microbiology of Marine Food Products', Ward, D. R., Hackney, C. (eds.), *Van Nostrand Reinhold*, New York, Chap.17, 429-440.

Gunes G. & Tekin M. D. 2006. Consumer Awareness and Acceptance of Irradiated Foods: Results of A Survey Conducted on Turkish Consumers. *Lebensmittel Wissenschaft und Technologie*, 39, 443–447.

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. *Radiat. Phys. Chem*. 130, 259-264.

Halkman H.B.D., Kozat P., Başbayraktar V., Çetinkaya N. 2010. Effect of Irradiation on Microorganisms, *Turkish Atomic Energy Agency* (TAEK),

Halkman A.K., Doğan H.B. & Noveir M.R. 2001. *Escherichia coli* O157:H7 Serotipi. *Orkim Ltd. Publications*, Sim Printing Ltd. Ankara, pp. 44.

Halkman H.B.D. & Kozat P. 2005. Effects of Radiation Applications in Foods on Microorganisms. *Food Journal, (GTD Yayın Organı*) 30(6), 409-416.

Hayashi T., Todoriki S. & Kohyama K. 1994. Irradiation Effects on Pepper Starch Viscosity. *J. Food Sci*. 59(1);118-120.

Hoefer D., Malone S., Frenzen P., Marcus R., Scallan E. & Zansky S. 2006. Knowledge, Attitude, And Practice of The Use of Irradiated Meat Among Respondents to The Foodnet Population Survey in Connecticut And New York. *Journal of Food Protection*, 69(10), 2441–2446.

ICGFI 1998. Monograph on Irradiation of Fish, Shellfish and Frog Legs, International Consultative Group on Food Irradiation, *International Atomic Energy Agency*, Vienna.

Kamarei A. R., Karel M. & Wierbicki E. 1979. Spectral Studies on The Role of Ionizing Radiation in Color Changes Of Rappertized Beef. *J. Food Sci.*, 44, 25- 31.

Kima Y.H., Namb K.C. & Ahn D.U. 2002. Volatile Profiles, Lipid Oxidation and Sensory Characteristics of Irradiated Meat from Different Animal Species. *Meat Sci.* 61, 257–265.

Lacroix M., Jobin M., Latreille B., Lapointe M. & Gagnon M. 1991. Hot-Water Immersion and Irradiation Effect on Mangoes Keeping-Quality After Air Shipment from Thailand to Canada. Microbiol. *Aliments Nutr.*, 9, 155-160.

Lagunas-Solar M.C. 1995. Radiation Processing of Foods: An Overview of Scientific Principles and Current Status. *J.Food Prot*., 58, 2, 186-192.

Lee J.H., Sung T.H., Lee K.T. & Kim M.R. 2004. Effect Of Gamma-Irradiation on Color, Pungency and Volatiles of Korean Red Pepper Powder. *Journal of Food Science*. 69, 585-592.

Loaharanu P. & Thomas P. 2001. Irradiation For Food Safety and Quality. *Crc Press.,* p. 217, Lanchaster.

Lung H.M., Cheng Y.C., Chang Y.H., Huang H.W., Yang B.B. & Wang C.Y. 2015. Microbial Decontamination of Food by Electron Beam Irradiation. *Trends FoodSci. Technol*. 44, 66-78.

Mayer M. E. 1993. Food Irradiation- A Means of Controlling Pathogenic Microorganisms in Food. *LWT - Food Science and Technology*. 26, 493-497.

Mermelstein, N. H. 2000. E-Beam-Irradiated Beef Reaches the Market, Papaya and Gamma-Irradiated Beef to Follow. *Food Technol.,* 54(7), 88-92.

Merritt Jr C., Angelini P. & Graham R.A. 1978. Effect Of Radiation Parameters on The Formation of Radiolysis Products In Meat And Meat Substances. *J. Agric. Food Chem.,* 26, 29-35.

Merritt Jr C., Angelini P., Wierbicki E. & Shults G. W. 1975. Chemical Changes with Flavor in Irradiated Meat. *J. Agric. Food Chem.,* 23, 1037-1044.

Mitchell G.E. 1994. Irradiation Preservation of Meats. *Food Australia*. 46, 512–516.

Molins R. 2001. Food Irradiation: Principles and Applications, *Wiley/Interscience,* Molins R(ed.). pp.469, New York.

Molins R. A., Motarjemi Y. & Kaferstein F. K. 2001. Irradiation: A Critical Control Point in Ensuring the Microbiological Safety of Raw Foods, *Food Cont.*, 347-356.

Monk J. D., Beuchat L. R. & Doyle M. P. 1995. Irradition Inactivation of Foodborne Microorganisms. *J. Food Prot.,* 58(2), 197-208

Nayga R. M., Poghosyan A. & Nichols J. P. 2004. Will Consumers Accept Irradiated Food Products?. *International Journal of Consumer Studies*, 28(2), 178–185.

Oliveira I. B. & Sabato S. F. 2002. Brazillaian Consumer Acceptance of Irradiated Food. *ANES.*

Olson D. G. 1998. Irradition Of Food. *Food Technol*., 52(1), 56-62.

Patterson M. F. 1995. Sensitivity of *Campylobacter spp.* to Irradiation in Poultry Meat, *Lett. Appl. Microbiol*., 20(6), 338-40.

Piggott J.R. & Othman Z. 1993. Effect of Irradiation on Volatile Oils of Black pepper. *Food Chem.* 46(2), 115-119.

Resurreccion A.V.A., Galvez F.C.F., Fletcher S.M. & Misra S.K. 1995. Consumer attitutes toward irradiated food-results of a new study. *Journal of Food Protection.,* 58 (2), 193-196.

Roberts P.B. 2016. Food Irradiation: Standards, Regulations and World-Wide Trade. *Radiat. Phys. Chem*. 129, 30–34.

Sagoo S.K., Little C.L., Greenwood M., Mithani V., Grant K. A. & Mclauchlin J. 2009. Assessment Of the Microbiological Safety Of Dried Spices And Herbs From Production And Retail Premises In The United Kingdom. *Food Microbiol*. 26(1), 39-43.

Sarıbay M.U. 2017. Food Irradiation Applications. *1. Agricultural and Food Ethics Congress*. Ankara.

Schweiggert U., Schieber R. & Schieber A. 2007.Conventional and Alternative Processes for Spice Production - A Review. *Trends Food Sci. Technol*. 18(5), 260-268.

Sirnik, M. & Jamsek, J. 1981. Sterilization of Spices and Spice Blends. *Tehnologija Mesa*, 22(1), 19-22.

Singh H., 1992. Control of Salmonella and Other Pathogenic and Spoilage Microorganisms in Poultry by Gamma and Electron Irradiation, *(AECL)Atomic Energy of Canada Limited.* Pinava, Manitoba.

Sudha Rao V., Gholap A.S., Adhikari H. & Madhusudanan Nair P. 2000. Disinfestation of Basmati Rice by The Use Of Γ-Radiation. *Int. J. Food Sci. Technol.*, 35, 533-540.

Szabad J. & Kiss I. 1979. Comparative Studies on the Sanitizing Effects of Ethylene Oxide and of Gamma Irradiation in Ground Paprika. *Acta Alimentaria*, 8(4), 383-395.

Thayer D. W. & Boyd G. 2001. Effect Of Irradition Temperature on Inactivation of *Escherichia Coli* O157:H7 and *Staphylococcus Aureus*. *J. Food Prot.*, 64(10), 1624-1626.

Thayer D. W. 1995. Use of Irradiation to Kill Enteric Pathogens on Meat and Poultry, *J. Food Safe.*, 15(2),181-192.

Turkish Atomic Energy Authority (TAEK) 2004. Food Irradiation Course, Ankara http://www.taek.gov.tr/tr/component/re (Accesible:14.03.2018)

UN News. 2017. https://news.un.org/en/story/2018/09/10 19002, (Accesible: 5.3.2019)

Vickers Z. M. & Wang J. 2002. Liking of Ground Beef Patties Is Not Affected by Irradition. *J. Food Sci.*, 67(1), 380- 383

Webb M. & Penner K. 2000. Food Irradiation, *Kansas State University*, http://hdl.handle.net/2097/21767 (accessed:6.2.2019)

WHO (World Health Organisation) 1999. High-Dose Irradiation: Wholesomeness of Food Irradiated with Doses above 10 kGy, *Report of a Joint FAO/IAEA/WHO Study Group*, Geneva, pp.197

WHO. 1994. Safety and Nutritional Adequacy of Irradiated Food. *World Health Organisation*. Geneva. Pp.176.

Wilcock, A. M. Pun, J. Khanona & M. Aung .2004. Consumer Attitudes, Knowledge and Behaviour. *Trends of Food Science and Technology* 15 (2), 55-66.

World Healt Organization (WHO) 2005. www.who.Int/media centre/fsctsheets/. IAEA (International Atomic Energy Agency) 2001.Irradiation To Ensurethe Safety And Quality Of Prepared Meals, Vienna, Austria, pp. 375.

Yılmaz H.Ö. & Ülger T.G. 2016. Effects of Food Irradiation on Food, *Ankara Health Sciences Journal*, (1-2-3), 1-16