8. ULUSLARARASI19 MAYIS YENİLİKÇİ BİLİMSEL YAKLAŞIMLAR KONGRESİ

23-24 Kasım 2022, Samsun

KONGRE KİTABI

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Doç. Dr. Nilgün ULUTAŞDEMİR
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IRRADIATION OF FISH AND FISH PRODUCTS – OPPORTUNITIES AND PERSPECTIVES

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ABSTRACT

In the constant struggle of the human population with the factors that contaminate and spoil food, treating food with ionizing radiation is becoming a more common trend, offering many advantages compared to traditional methods of food preservation. Regarding fish and fish products, this procedure is becoming an increasingly common choice, allowing non-thermal preservation of their stability. This paper presents the reasons for choosing irradiation in maintaining microbiological safety and extending the shelf life of fish and fish products, the doses recommended by the relevant international institutions, examples from practice, changes in organoleptic characteristics depending on the dose of irradiation, a comparison of the legislation in the countries that allow the treatment of this type of food with irradiation and a presentation of the standards and methods for the detection of treated fish and fish products. In the extensive literature found on this issue, it is noted that treating fish and fish products with ionizing radiation is a regular procedure in the USA and Asian countries, which are the largest consumers of this type of food. While doing so, choosing the optimal dose of irradiation is of primary importance due to the appearance of unpleasant odors and tastes that make them unacceptable to consumers.

Keywords: *irradiation, fish and fish products, shelf life*

Introduction

Regarding treating food with ionizing radiation, a considerable number of papers have been published and extensive research has been conducted confirming the safety and numerous advantages of this procedure (Diehl, 1995; WHO, 1981; WHO, 1994). In humanity's constant struggle with factors that contaminate and spoil food (especially when it comes to food that is stored for a certain period and intended for later use), this method has proven to be one of the most useful. At the same time, among the various types of food that are treated with ionizing radiation, fish and fish products are regularly found. This is because this type of food is a very important source of protein in the human diet, but unfortunately, it has a very short shelf life after harvesting, so it must be properly treated (Kilgen, 2000). Although the most commonly used methods for preserving the quality of fish and fish products are the methods of cooling, freezing, packaging with a modified atmosphere, roasting, salting, drying, and fermentation, treating them with ionizing radiation is becoming a more proven non-thermal way to maintain their stability and safety (Boziaris, 2014). Moreover, using ionizing radiation for this purpose is a suitable method for the deactivation of pathogenic microorganisms in them without significantly affecting their sensory characteristics (Gautam & Venugopal, 2021).

Fish and fish products undergo numerous biochemical changes after their harvesting, which is the reason they need to be treated immediately to ensure their optimal quality (Boziaris, 2014). Otherwise, rapid microbial development will cause the creation of various compounds (amines, sulfides, alcohols, aldehydes, ketones, and organic acids), which will make them unacceptable for consumption (Gram & Dalgaard, 2002). This kind of rapid spoilage is especially characteristic of marine species, due to the high concentration of nitrogen compounds in them, as well as the low acidity (pH > 6), which accelerates the development of microorganisms in them. At the same time, the fats that are represented in a high percentage are subjected to chemical oxidation, which is one of the main factors for the deterioration of their quality (Ashie *et al.*, 1996). Moreover, the fats found in fish and seafood are characterized by a high percentage of polyunsaturated fatty acids (PUFAs), which makes them particularly oxidatively labile (Armstrong *et al.*, 1994). In that direction, treating fish and fish products with ionizing radiation is a method that effectively deactivates the enzymes that initiate these processes (Boziaris, 2014).

In the context of the knowledge that food of animal origin is the primary cause of numerous diseases and infections, it can be pointed out that fish and fish products can be carriers of many pathogenic species. Therefore, their microbiological safety is generally determined by the presence or absence of several non-sporogenous pathogenic bacteria such as *Salmonella, Shigella, E.coli, Staphylococcus aureus, Vibrio cholerae,* and *Vibrio parahaemoliticus,* as well as (although rare), the sporogenous genus *Clostridium* (Bögl, 1988). At the same time, very often specific types of microorganisms (SSO) develop in them. These microorganisms initially participate with a very small percentage of the microbial flora, but subsequently multiply very rapidly, becoming a dominant community with a high potential for spoilage. So, for example, gram-negative, fermentative bacteria from the *Vibrionaceae* family are the most common spoilage of untreated fish, while psychrotolerant gram-negative bacteria *Pseudomonas spp.* and *Shewanella spp.* usually develop on chilled fish. Therefore, inhibiting the growth and development of such specific microorganisms is the main point for extending the shelf life of fish and fish products (Gram & Dalgaard, 2002).

The beneficial effects of treating fish and fish products with ionizing radiation have been confirmed mainly for frozen fish and fish products. This treatment offers the best protection against potential sources of pathogenic microorganisms that may already be present in them, but which may also be introduced during further processing procedures or their packaging (Kilgen, 2000).

As a result of these findings, preserving the quality of fish and fish products by treating them with ionizing radiation was among the first proposals by the Regional Agreement for Research, Development and Training Related to Nuclear Science and Technology (RCA), which became operational in June 1972 (Vas, 1974). Moreover, the first literary record of treating fish with ionizing radiation was presented in 1950 (Nickerson *et al.*, 1983).

Based on these findings, this paper analyzes the reasons for choosing ionizing irradiation in maintaining microbiological safety and extending the shelf life of fish and fish products, the doses recommended by the relevant international institutions, examples from practice, changes in sensory qualitative characteristics depending on the dose of irradiation, a comparison of the legislation in the countries that allow treating this type of food with irradiation and standards and methods used for detection of treated fish and fish products.

Doses of ionizing radiation that are recommended for treating fish and fish products

When choosing the optimal dose for treating fish and fish products with ionizing radiation, there are several selection criteria: the desired goal, the absence of noticeable sensory qualitative changes that may occur during the treatment, as well as the desired storage period, and storage temperature (Bögl, 1988). In this context, low doses of ionizing radiation from 0.2 kGy to 1 kGy are applied for insect disinfestation in dried fish products (IAEA, 2002; Miller, 2005), medium doses from 1 kGy to 10 kGy are used to extend the shelf life and microbiological safety of fish and fish products, but mostly, for this type of food, doses from 2 kGy to 8 kGy are considered to be most suitable in practice (IAEA, 1985).

Table 1 shows the maximum permissible doses for treating fish and fish products, recommended by the IAEA (2002), according to the purposes for which the treatment is carried out. It can be noted that the minimum required dose is 3.0 kGy, and the maximum allowed dose does not exceed 5.0 kGy.

Based on these recommendations, in Table 2, the maximum permitted doses in EU member states that carry out this treatment are presented. Following the Directive 1999/2/EC (on the treatment of fish and seafood with ionizing radiation) it can be noted that the maximum average absorbed doses (kGy) according to European Union legislation range between 3 kGy to 5 kGy.

Table 1. Advisory technological dose limits (IAEA,2002)

	Purpose	Maximum dose (kGy)	ICGFI document No
Fish, seafood and their products (fresh or frozen)	Reduction of certain pathogenic microorganisms	5.0	10
	Shelf life extension	3.0	10
	Control of infection by parasites	2.0	10

Table 2. Authorized absorbed dose according to Directive 1999/2/EC (Boziaris, 2014)

European Union Member State	Given maximum average absorbed dose (kGy) according to European Union legislation		
	Fish and shellfish (including eels, crustaceans and molluscs)	Frozen, peeld or decapitated shrimps	Shrimps
Belgium	3	5	-
France	-	5	-
Netherlands	-	-	3
United Kingdom	3	-	-

However, if a comparison is made worldwide, there are many differences between different countries regarding the maximum approved doses, as well as in the way fish and fish products are labeled (Table 3). Therefore, it can be concluded that one of the biggest challenges faced by the global food sector in the use of ionizing radiation to treat food, is the need to harmonize regulations and the equivalence of standards, doses, and labeling of food that can be treated at this way (GHI, 2018).

Table 3. Differences in the way of labeling and maximum absorbed dose limitations for fish and fish products irradiation in different countries (GHI, 2018)

Country	Legislation	Labeling	Purpose and maximum absorbed dose limitation
USA	21 CFR 179	Fresh shell eggs	Not to exceed 3 kGy
		Fresh or frozen molluscan shellfish	Not to exceed 5.5 kGy
Bangladesh	Bangladesh Government 1983. Revised Codex General Standard for	Fish	Microbial control max 2.2 kGy
		Dry fish	Disinfestation max 5 kGy

	Irradiated Foods, Codex Stan 106, 1983	Fish products	Microbial control, shelf-life extension max 7 kGy
India	Food Safety and Standards Act 2006 and Atomic Energy Rules 2012	Fish, aquaculture, seafood and their products (fresh/frozen)	Elimination of pathogens 1.0 -7.0 kGy Shelf life extension 1.0 - 3.0 kGy Control of human parasites 0.3 - 2.0 kGy
Indonesia	Government regulation, 1999 on food labeling and advertisement; Government regulation 2004 food safety, quality and nutrition; Food Act 18, 2012	Fish and seafood (fresh and frozen) Processed fish products and seafood	Reduce pathogenic microorganisms 5.0 kGy Extend shelf life 3.0 kGy Controlling infection 2.0 kGy Reduce pathogenic microorganisms 8.0 kGy Extend shelf life 10 kGy
Malaysia	Food Irradiation Regulations 2011	Fish and fish products and frog legs	Reduction of pathogens 1.0 - 7.0 kGy Shelf life extension 1.0 - 3.0 kGy Control of infection by parasites 0.1- 2.0 kGy Insect disinfestation 0.3 -1.0 kGy
Pakistan	Unknown	Raw fish, seafood and their products (fresh/frozen)	Reducing pathogens 5.0 kGy Shelf life extension 3.0 kGy
Vietnam	Decision 3616/2004/QD-BYT for safety and sanitation of 7 foods by irradiation (Guidelines by Ministry of Health)	Aquatic food and its products including spineless, amphibian animals (fresh or frozen)	Reduction of pathogens 1.0 - 7.0 kGy Shelf-life extension 1.0 - 3.0 kGy Control of infection by parasites 0.1 - 2.0 kGy

The general finding is that the maximum permitted dose in almost all regulations does not exceed 7 kGy. This is also confirmed by the finding of Morehouse (1998), according to which doses from 2 kGy to 7 kGy are considered the most appropriate for the reduction of pathogenic microorganisms, as well as for extending the shelf life of fish and fish products.
In that direction, in Table 4, an analysis of examples from practice in which fish and fish products have been treated with different doses of ionizing radiation is made.

Table 4	Examples from practice (adapted from Boziaris, 2014)			
Irradiation dose (kGy)	Fish species	Aim/Effect	Shelf life (days)	References
0.66 kGy	*Urophycis chuss*	Total aerobic plate counts of the control and irradiated samples remained less than 10^6 CFU/g	6–13 more than non-irradiated	Dymsza *et al.*, 1990
0.82 kGy	*Coregonus clupeaformis*	TBA number (thiobarbituric acid test) remained within acceptable limits in all samples	Two-fold shelf-life extension	Chuaqui-Offermanns *et al.*, 1988
1 kGy	*Oreochromis niloticus*	The irradiated samples had a microbiological content below the levels established by the Brazilian seafood legislation	Irradiated samples remained stable for 20 and 30 days	Cozzo-Siqueira *et al.*, 2003
	Trachurus picturatus	The microbial content remains below the limit of acceptability. 1 kGy was sufficient of delaying volatile amines production	Unacceptable after 8 days	Mendes *et al.*, 2000
	Mugil nuema	Parasites' motility from 100 % to 15 %	-	Antunes *et al.*, 1993
	Melanogrammus aeglefinus (filleted after 2 days in ice)	1 kGy reduced the total bacterial count by approximately 1 log order. *Achromobacter* reduced by about 1 log order *Pseudomonads* reduced between 2 to 3 log orders	9-18	Laycock & Regier, 1970
	Perca flavescens	1.4 log reduction of the initial Count. Pseudomonas eliminated.	18	Kazanas & Emerson, 1968
	Oncorhynchus mykiss fillets	Reduction of total viable counts from 4.41 log CFU/g to 3.08 log CFU/g. The total reduction of H_2S-producing bacteria. Reduction of *Enterobacteriaceae* from initial count 3.29 log CFU/g to 2.29 log CFU/g	21-28	Moini *et al.*, 2009
1.22 kGy	*Coregonus clupeaformis*	TBA number (thiobarbituric acid test) remained within acceptable limits in all samples	Three times longer than the unirradiated fish	Chuaqui-Offermanns *et al.*, 1988
1.31 kGy	*Urophycis chuss*	Total aerobic plate found to be less than 10^6 cfu/g for 4, 10, and 17 days after irradiation at all doses	6-13	Dymsza *et al.*, 1990
	Tilapia nilotica,	The population of H_2S producing		

1.5 kGy	*Tilapia aurea Scomberomorus commerson*	bacteria remained low throughout the storage period. Elimination of *Yersinia* and *Salmonella* spp.	-	Abu-Tarboush *et al*., 1996
2 kGy	*Bigeye snapper – Priacanthus tayenus*, a Thai fermented fish mince	No Lactic acid bacteria (LAB), yeast and mold counts growth was found in the sample irradiated at 2 kGy within the first 10 days	-	Riebroy *et al*., 2007
	Trachurus picturatus	The microbial content remains below the limit of acceptability	8 days	Mendes *et al*., 2000
	Sillago sihama	Elimination of *Vibrio parahaemolyticus* and *Staphylococcus aureus*. Elimination of *Yersinia* sp and Listeria sp.	19	Ahmed *et al*., 1997
	Mugil nuema	Motility decrease of *Phagicola longa* parasites from 100 % to 17 %	-	Antunes *et al*., 1993
	Mugil plutunus	Motility decrease of *Phagicola longa* parasites from 56 % to 31 %	-	Antunes *et al*., 1993
	Merluccius merluccius hubi	1 log cycle reduction in bacterial number versus the controls	6 weeks	Valdes & Szeinfeld, 1989
	Perca flavescens	3 log reduction of the initial count	18	Kazanas & Emerson, 1968
2.2 kGy	*Oreochromis niloticus*	Irradiated samples had a microbiological content below the levels established by the Brazilian seafood legislation	During storage, 0.5°C to −2°C for 20 and 30 days, the level of moisture in the irradiated samples remained stable	Cozzo- Siqueira *et al*., 2003
2.5 kGy	*Dicentrarchus labrax*	The higher the irradiation dose the lower the population of psychrotrophic bacteria, mesophilic aerobic bacteria, H_2S-producing bacteria, *Enterobacteriaceae* and Pseudomonas	15	Ozden *et al*., 2007
	Mugil plutunus	Motility decrease of *Phagicola longa* parasites from 56 % to 9 %	-	Antunes *et al*., 1993
	Trachurus picturatus	Between control and 3 kGy samples, bacterial loads varied from 4.75 to 3.3 log 10/g in the skin and from 4.4 to 3.00 log 10/g in the muscle	4-5 days extended	Mendes *et al*., 2000

3 kGy	Golden anchovy (0.39 % fat)	*Listeria monocytogenes* 036, *Yersinia enterocolitica* F5692, *Bacillus cereus* and *Salmonella typhimurium* had no difference in their survival	-	Kamat & Thomas, 1998
	Indian sardine (7.1 % fat)	*Listeria monocytogenes* 036, *Yersinia enterocolitica* F5692, *Bacillus cereus* and *Salmonella typhimurium* had no difference in their survival	-	Kamat & Thomas, 1998
	Sillago sihama	*Salmonella sp*. was not detected. Elimination of *Listeria* sp and *Yersinia sp*.	19	Ahmed *et al*., 1997
	Tilapia nilotica, Tilapia aurea Scomberomorus commerson	Elimination of *Campylobacter*	8 more than non-irradiated	Abu-Tarboush *et al*., 1996
	Mugil plutunus	Motility decrease of *Phagicola longa* parasites from 56 % to 18 %	-	Antunes *et al*., 1993
	Perca flavescens	Nearly 100 % reduction of microbial count	43	Kazanas *et al*., 1966
	Oncorhynchus mykiss fillets	Reduction of total viable counts from 4.41 log CFU/g to 1.46 log CFU/g. The total reduction of H_2S-producing bacteria. Reduction of *Enterobacteriaceae* from initial count 3.29 log CFU/g to 1.45 log CFU/g	21-28	Moini *et al*., 2009
3.5 kGy	*Mugil plutunus*	Motility decrease of *Phagicola longa* parasites from 56 % to 5 %	-	Antunes *et al*., 1993
4 kGy	*Mugil nuema*	*Phagicola longa* metacercaria inviability	-	Antunes *et al*., 1993
	Mugil plutunus	Control dose for *Phagicola longa*	-	Antunes *et al*., 1993
4.5 kGy	*Tilapia nilotica, Tilapia aurea Scomberomorus commerson*	No growth of Coliforms in the skin and meat of irradiated Tilapia	8 more than non-irradiated	Abu-Tarboush *et al*., 1996
	Dicentrarchus labrax	The higher the irradiation dose the lower the population of psychrotrophic bacteria, mesophilic aerobic bacteria, H_2S-	17	Ozden *et al*., 2007

5 kGy		producing bacteria, *Enterobacteriaceae* and pseudomonads		
	Oreochromis niloticus	Irradiated samples had a microbiological content below the levels established by the Brazilian seafood legislation	During storage from 0.5°C to −2°C for 20 and 30 days, the level of moisture in the irradiated samples remained stable	Cozzo- Siqueira *et al*., 2003
	Oncorhynchus mykiss fillets	The total reduction of total viable counts, the total reduction of H_2S-producing bacteria, the total reduction of *Enterobacteriaceae* from an initial count of 3.29 log CFU/g	28-35	Moini *et al*., 2009
6 kGy	*Bigeye snapper – Priacanthus*, a Thai fermented fish mince	Lactic acid bacteria (LAB), yeast and mold counts in samples irradiated at 6 kGy were not detectable throughout the storage of 30 days	-	Riebroy *et al*., 2007
	Tilapia nilotica, Tilapia aurea Scomberomorus commerson	Reduction in psychrotrophic counts	The odor and the texture of cooked Spanish mackerel was badly deteriorated	Abu-Tarboush *et al*., 1996
	Perca flavescens	Nearly 100% reduction of microbial count. Progressively lower maximal bacterial populations and lengthened lag phases were obtained as more radiation was used	-	Kazanas *et al*.,1966
	Merluccius merluccius hubi	Bacterial counts well below the minimum acceptable level of 0.8 x 10^6 bacteria per gram for the entire seven-week study period	6 weeks	Valdes & Szeinfeld, 1989
10 kGy	*Merluccius merluccius hubi*	Bacterial counts well below the minimum acceptable level of 0.8 x 10^6 bacteria per gram for the entire seven-week study period	6 weeks	Valdes & Szeinfeld, 1989
	Mugil nuema	*Phagicola longa* metacercaria inviability	-	Antunes *et al*., 1993
	Tilapia nilotica,		The odor and the texture of	

	Tilapia aurea *Scomberomorus commerson*	Reduction in psychrotrophic counts	cooked Spanish mackerel badly deteriorated	Abu-Tarboush *et al*., 1996

From the data shown in Table 4, it can be noted that in all the cases mentioned, the reasons for treating fish and fish products with ionizing radiation are: microbiological safety and extending the shelf life. At the same time, it can be concluded that the second reason determines the maximum sufficient dose, because one of the most important conditions for good quality fish and fish products is their fresh taste, without any sensory qualitative changes. In that direction, although there are different microbiological, biochemical, and physical methods for detecting possible deterioration in the quality of fish and fish products, sensory qualitative changes are the best indicator for its assessment (Moini *et al.*, 2009).
This is because, similar to when treating meat with ionizing radiation, unwanted sensory changes may occur in fish and fish products also. Therefore, it is not desirable to treat most fresh fish and fish products with doses higher than 3 kGy, although regulations in many countries allow doses up to 5 kGy. An exception can be made for a smoked and very fatty fish (such as mackerel), where sensory qualitative changes may not be noticeable due to its relatively strong smell and taste (Bögl, 1988). According to Vas (1974), the safekeeping of fish can be significantly prolonged even with small doses of ionizing radiation, such as doses of 1-2 kGy, without any noticeable changes in their sensory qualitative characteristics (taste, smell, texture, and appearance). In that direction, Armstrong (1994) states that ionizing radiation usually creates a characteristic "burnt" taste and smell, but it depends on the type, dose, and lipid component in the fish. Therefore Nickerson *et al*., (1983) suggest determining the appropriate dose of ionizing radiation for each type of fish and fish products, that will maintain their quality and ensure extended shelf life. Until then, the general recommendation for treating fish and fish products is to use doses of ionizing radiation, with maximum amounts of up to 2-2.5 kGy, to avoid possible sensory qualitative changes.

Methods for detection of irradiated fish and fish

Since treating food with ionizing radiation (when applied in permissible and optimal doses) does not cause visual and sensory changes in food, there is a need for reliable procedures and methods for detecting if one product has been irradiated. At the same time, there is always the dilemma of "whether such a product is treated with a permissible and optimal dose". In recent decades, great progress has been made in finding methods suitable to identify foods treated with ionizing radiation. Based on such knowledge, within the European Standards for irradiation detection of food (approved by the European Committee for Standardization (CEN)), there are ways to prove the treatment of fish and fish products treated with ionizing radiation also.
In Table 5 the Standards that can be used when determining fish and fish products irradiation are presented. It can be stated that, in contrast to the other types of food, for fish and fish products there is no single detection method, nor a standard that could be applied to a larger number of fish species. So, although great progress has been made in finding ways to detect food irradiation in recent decades, for fish and fish products generally physical methods can be used to detect if they have been irradiated.

Table 5. EN standards application for irradiation detection in food

Method	Standard	Determination methods	Identified compounds	Applied successfully in foods
Physical methods	EN 1786:1996	ESR (Electron Spin Resonance)	Paramagnetic compounds	Beef bones, **trout bones**, chicken bones
	EN 1788:2001	TL (Thermoluminscence)	Silicate minerals	Herbs, spices, **prawns**, fresh and dehydrated fruits and vegetables, potatoes
	EN 13751:2002	PSL (Photostimulated luminescence)	Mineral debris	**Shellfish**, herbs, spices and seasonings
Chemical methods	EN 1785:2003	GC/MS	DCB (dodecylcyclobutanone) TCB (tetradecylcyclobutanone)	Raw chicken, pork, liquid whole egg, **salmon**, camembert
Biological methods	EN 13784:2001	DNA comet assay Electrophoresis time and field strength	Microgel electrophoresis	Chicken (duck, quail, pheasant, pork, beef, veal, lamb, deer), **fish (trout, salmon),** almonds, figs, lentils, soybeans, strawberries, sesame seeds, rose pepper

Conclusion

Fish and fish products are subject to various procedures for preserving their optimal quality, which is based on the deactivation of the growth and development of various species of microorganisms and the prevention of biochemical changes after their harvesting. Among them, using ionizing radiation to inhibit microbiological growth and extend their shelf life has proven to be very effective. However, choosing the optimal irradiation dose is generally influenced by the appearance of undesirable sensory qualitative changes that are generally unacceptable to consumers. At the same time, there is an inconsistency in recommended doses and terms for labeling this type of food in different countries. In general, the practice has shown that until the optimal dose of ionizing radiation is determined for each fish species individually, the recommended maximum dose must not exceed 7 kGy, while the optimal doses for most fish species range between 3 kGy and 5 kGy. In parallel with that, although great progress has been made in finding ways to detect food irradiation in recent decades, generally physical methods can be used to monitor fish and fish products. So, it can be concluded that, in contrast to the other types of food, for fish and fish products there is no single detection method, nor a standard that could be applied to a larger number of fish species.

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