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RADIOBIOLOGY, ECOLOGY AND NUCLEAR MEDICINE

Applying Low Energy Electrons to Irradiate Chilled Trout

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Abstract—The irradiation of minced chilled trout using a UELR-1-25-T-001 continuous-action electron accelerator with an energy of 1 MeV has been studied. Here, we present the results of the effect of electrons at doses of 0.24, 0.48, 0.96, 2.8, and 5.6 kGy on the viability of microorganisms in the minced trout. It has been experimentally shown that electron irradiation generated by the accelerator at doses of 0.24 to 5.6 kGy decreases microbial abundance in minced trout, in comparison with untreated samples, 15 days after irradiation, and makes it possible to control the microbial contamination of chilled fish products within 2 weeks after irradiation.

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INTRODUCTION

Extending the storage life of food products while preserving their quality is a crucial task. The solution to this problem will increase domestic production and reduce import demand. Food additives and preservatives, fumigants, and other chemicals are traditionally used to extend the shelf life of products. However, these chemicals are potentially dangerous for human health, and the global trends are toward the prevention of their use. At present, treating food products with ionizing radiation is one of the most efficient and environmentally friendly technologies used to guarantee the safety of food products and to extend their storage life. According to IAEA, the use of irradiation for more than 80 types of products has been approved in 69 countries. More than 200 centers specialized in the industrial treatment of certain categories of food products and agricultural raw materials have been created [1]. Annually, the average total volume of irradiated food products is 400000 t, and the demand for this service keeps growing every year [2–4]. Compared to other methods of treatment, this technology makes it possible to replace or dramatically reduce the use of food preservatives and prevents an increase in the temperature of the processed product; it is also less energy consuming when compared to other methods [5]. Its introduction into the general technological process of food production is widely used throughout the world [3, 6–8].

Electron irradiation with an energy of ≤10 MeV and gamma irradiation of ^{60}Co ($T_{1/2}$ = 5.27 years; E = 1.25 MeV) and ^{137}Cs ($T_{1/2}$ = 30.17 years, E = 0.66 MeV) radioisotopes, as well as bremsstrahlung irradiation generated by electron accelerators with an energy of ≤5 MeV, are approved physical effects of the irradiation treatment of food products [9]. According to IAEA, the total number of gamma radiation sources and electron accelerators used for the irradiation treatment of food products is approximately 2000 units [3]. The selection of upper energy limits for electron and gamma radiation is explained by the requirements to exclude the formation of radionuclides of induced activity, which are generated in photonuclear reactions, in food products [6]. At the same time, numerous studies have shown that hazardous concentrations of radiolysis products are not formed in food products at radiation doses below 10 kGy, which are recommended by international and domestic regulatory documents [6].

An analysis of scientific studies has shown that the effect of exposure to any sources of ionizing radiation listed above is generally stable and prolonged for spices and dried vegetables and fruit. At the same time, the result of irradiation treatment of fish and meat (including poultry) depends on various factors, such as storage temperature, initial composition of microflora, total microbial abundance, pH, chemical composition, type of packaging, the presence of preliminary heat treatment, food preservatives and additives, bones, and others [8, 13–15].

Much attention is paid to changes in the chemical composition of products during long-term storage after exposure to ionizing radiation and, as a result, to changes in its organoleptic characteristics [13, 17, 18]. The effect of electron radiation at doses of 1–3 kGy does not lead to significant changes in chemical parameters of the products (in the pH value, in partic-

ular) immediately after treatment. However, during storage, these characteristics significantly change in comparison with the control indicators, which greatly affects the organoleptic properties of the products.

Studies on the survival of various bacterial species in meat and fish products depending on the doses and types of ionizing radiation are carried out [18–21]. Doses that cause a pronounced decrease in the abundance of bacterial populations in physiological saline are significantly different from those for bacteria present in the products [20]. Different strains of the same bacterial species differ in radiosensitivity when they enter the culture medium [19].

Everlasting scientific interest in the effects of various doses of ionizing radiation on the microbiological, physicochemical, and organoleptic properties of food products and the search for optimal parameters for the irradiation treatment of various types of products indicate the current importance of the research in this field. This is also confirmed by the adoption of technical regulations and GOST Russian National Standards for irradiation treatment of food products, as well as the creation of new innovative centers for irradiation treatment in Russia.

This research was devoted to the study of the effect of different doses of accelerated electrons with an energy of 1 MeV on the microbiological parameters of chilled trout.

MATERIALS AND METHODS

Chilled coastal rainbow trout was the object of this study. Physiological saline was added to the minced trout in a ratio of 1 : 3 and homogenized until a homogeneous suspension was obtained. The homogenate of minced trout (0.5 mL) was added to 2-mL sterile Eppendorf plastic tubes.

The samples were irradiated using a UELR-1-25-T-001 electron accelerator of continuous action with an energy of 1 MeV and an average beam power of 25 kW. The samples of the homogenate were placed on a duralumin plate at a distance of 12 cm from the output of the electron beam. During each irradiation, the charge incident upon the plate and the irradiation time were recorded. The electron beam flow remained constant in all experiments. The thickness of the minced fish was (2 ± 1) mm.

The dose absorbed by the test samples was assessed by the ferrous sulfate dosimetry method. The dosimeter solution was irradiated according to the scheme, which was similar to the irradiation of the samples of the homogenate of minced trout. The density of the minced fish homogenate was similar to the density of the dosimeter solution: (0.994 ± 0.05) and (1.024 ± 0.05) g/cm^3, respectively. Thus, the dose measured using a dosimeter solution was the same as the dose absorbed by the homogenate, when the volumes of the solution and the homogenate, as well as the irradiation conditions, were equal.

Therefore, the dose rate absorbed by the dosimeter solution, which was irradiated using the electron accelerator, was (25 ± 2) Gy/s, while the doses absorbed by the experimental samples of the minced fish were 0.24, 0.48, 0.96, 2.8, and 5.6 kGy.

The evenness of the irradiation was assessed using the GEANT 4 program code based on the Monte Carlo method. During the simulation, the initial spectrum of electron radiation at the accelerator output was taken into account; the number of electrons in the beam was 10^8. The simulated irradiation area was equated to the area of the duralumin plate on which the samples were placed. The geometric dimensions of the plate, which was a rectangular parallelepiped in shape, were also measured and were equal to $35.0 \times 3.0 \times 0.8$ cm. The density of the suspension of trout minced homogenate (0.994 ± 0.04) g/cm^3 was close to the density of water; water phantoms of the corresponding dimensions were therefore used as model samples. The characteristics of the tubes were taken into account (a polypropylene cylinder with a radius of 4.5 mm, length of 39 mm, and a wall thickness of 1 mm). The volume of water in the test tube was 0.5 cm^3, and the maximum thickness of the water layer was 2 mm. The program code included modeling all possible processes of interactions of electrons with the matter, the error in the determination of which did not exceed 2%. Based on the results of computer simulation, the range of electrons with an energy of 1 MeV in water was less than 5 mm. The evenness of the dose absorbed by the aqueous phantom (as thick as 2 mm) was 96%.

After irradiation treatment, the microbiological parameters of the irradiated and control samples, which were stored at 4°C for 15 days, were monitored every 3 days.

RESULTS AND DISCUSSION

Initially, the total number of viable bacteria in chilled trout was $(6.6 \pm 1.8) \times 10^3$ CFU/g. Figure 1 shows the dependence of the total abundance of viable cells in the samples irradiated with different doses of electrons on the time after irradiation. At the same time, the dynamics of changes in microbial contamination of the control unirradiated samples within 15 days from the beginning of experiments was also studied. According to Fig. 1, the kinetics of the changes in the cell numbers over time is nonmonotonic in all samples.

Fifteen days after the beginning of the study, the microbial abundance in the control samples increased to $(2 \pm 0.2) \times 10^8$ CFU/g. The microbial contamination of minced fish treated with electron irradiation

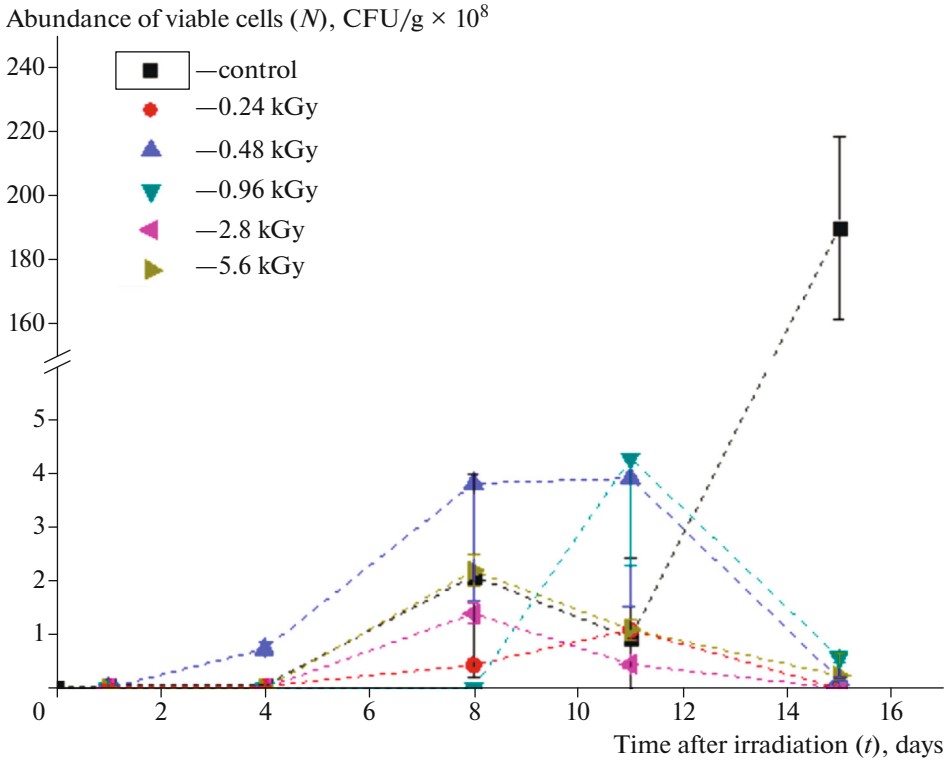

Fig. 1. Dependence of the total abundance of viable cells in the samples irradiated with accelerated electrons at doses of 0, 0.24, 0.48, 0.96, 2.8, and 5.6 kGy on the time of storage after irradiation.

(at all doses) did not exceed $(4 \pm 0.7) \times 10^6$ CFU/g during the entire observation period.

The dependence of the number of viable cells in the samples irradiated at doses of 0.24, 0.48, and 0.96 kGy on time was similar. On day 15, their microbiological indices decreased to 10^5 CFU/g and less, which corresponded to the maximum permissible level of microbial contamination of fish products.

Fifteen days after irradiation, the microbial abundance in the samples irradiated at doses of 2.8 and 5.6 kGy ranged within approximately 10^5–10^6 CFU/g.

It is noteworthy that a morphological analysis of the colonies plated from control samples showed their species diversity throughout the entire period of the product storage at 4°C. Colonies plated from the samples, which were irradiated at doses of 0.24 and 0.48 kGy, did not differ from control samples in diameter and consistency. Changes at a dose of 0.96 kGy were insignificant and were observed on the 11th day after irradiation. The colonies plated from minced trout, which was irradiated with doses of 2.8 and 5.6 kGy, showed significant changes in diameter and appearance. At the same time, these changes became more pronounced with an increase in storage time. Exposure to ionizing radiation changes the biochemical and morphological properties of microbial cells [22]. The degree of changes depends on many factors, including the radiosensitivity of this population. The development of several communities possessing different levels of radioresistance to ionizing radiation under the conditions of limited nutritional resources of minced fish occurs asynchronously, which explains the fluctuations in numbers of viable cells in irradiated samples during storage (Fig. 1).

According to the results of our study, electron irradiation at doses of 0.24–5.6 kGy was shown to reduce microbial contamination of the minced trout compared to unirradiated samples 15 days after irradiation. At the end of the study, the total microbial abundance in all irradiated samples did not exceed 10^6 CFU/g. At the same time, this indicator was more than 10^8 CFU/g in control samples. Thus, irradiation with low energy electrons makes it possible to control the microbial contamination of chilled fish products stored for 15 days at 4°C.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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