Ionizing radiation treatment as an innovative process approach in food storage technology for modern agriculture

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Abstract. The article presents the results of the identification of chilled imported rainbow trout to establish the fact of irradiation in the study of bone tissue by electron paramagnetic resonance (EPR) on a modern domestic EPR X-band spectrometer of Labrador Expert brand. It was established that imported trout was previously treated with ionizing radiation, and information on the processing method in violation of regulatory requirements was not communicated to consumers. Implementation of an innovative process approach when choosing a technology for processing food products with ionizing radiation allows us to provide high organoleptic characteristics during storage for up to 15 days, maintaining freshness indicators (acid number, peroxide number) at the normal level and prolonging shelf life. Proven processing efficiencies to ensure microbiological safety. The results are of practical and methodological importance for the implementation of radiobiological control of previously irradiated food products and the justification of the possibility of using ionizing radiation in the technological process at the enterprises of the agro-industrial complex to extend shelf life based on an innovative process approach to the choice of storage technologies.

1. Introduction

In the conditions of industrial production neo-industrialization of food products, the process approach to ensuring interaction at all stages of production in accordance with GOST R ISO 9001-2015 “Quality Management Systems. Requirements” plays a very important role.

At the same time, the main systemic problems that are characteristic of agricultural enterprises, along with the moral and physical deterioration of technological equipment at a number of enterprises, may include the use of mainly traditional food processing and storage technologies. Therefore, according to the Development Strategy of the food and processing industry of the Russian Federation for the period until 2020, measures for the development of the food and processing industry should be focused on solving the main systemic problems, the formation of a new industrial potential, modernization and innovative development.

Innovation in this case according to GOST R 56261-2014 “Innovation management. Innovation The main provisions” are defined as improving existing or creating completely new products, processes. They are divided into product, process, organizational and marketing innovations. At the same time, by their nature, they can be technological and non-technological.

According to [1], the main areas of innovation in food production sectors include: technological, assortment (production of new food products), marketing and organizational areas.
At the same time, a number of authors [2] characterize food and technological innovations as innovations in the food industry, and organizational and marketing innovations - as innovations in trade. Moreover, referring to “technological packaging” as “active packaging”, “innovative methods of production and processing of food products”, including high-pressure processing up to 600 MPa; shockwave treatment to soften the muscle tissue of animal raw materials, the so-called tendering; molecular cuisine; freeze-drying and Cook & Chill technology are classified as product innovations, which from our point of view is not entirely correct, since it is the introduction of new high-tech process innovations, as the basis of production, processing and storage technology, that will ensure the innovative development of food and food processing enterprises.

So, along with ultra-pasteurization [3,4], which affects the change in freshness, non-thermal methods of processing food products, including homogenization of liquid food products by pressure [5] are proposed. High-pressure treatment is proposed to suppress the vital activity of microorganisms [6-9]. High-voltage treatment arc discharge (HVAD-highvoltagearcdischarge) is used to improve the susceptibility of milk protein to further enzymatic hydrolysis [10] and inactivation of microorganisms [11], ultraviolet radiation [12].

The choice of the process approach to the processing of food products is determined by the goals and the type of food product itself. Fish and seafood are an important source of easily digestible edible protein, but require special storage conditions, since a high content of unsaturated fatty acids leads to oxidative damage if the temperature and humidity conditions are not observed. Fish preservation is traditionally ensured by exposure to low temperatures in air, when stored in clean ice or ice made from electroactivated water with the addition of arabinogalactan, and when a protective coating layer of their chitosan, sucrose and other types of food additives is applied [13-17].

An effective way to reduce microbiological contamination and ensure the preservation of the most demanded by modern consumers of chilled and fresh food products is the treatment of ionizing radiation. In contrast to foreign countries, the processing of fish and seafood is allowed only in February 2019 in accordance with the requirements of GOST 34154-2017 “Guidelines for the irradiation of fish and seafood with the aim of suppressing pathogenic and spoilage microorganisms”. According to the results of studies by foreign authors, irradiation of fish with gamma radiation at a dose of up to 0.5 kGy ensures its safety for up to 3 months. When the dose is increased to 9 kGy, DNA damage occurs [18].

At the same time, radiation treatment of oysters (Crassostrea brasiliana) with a dose of up to 3.0 kGy is effective for inactivation of Salmonella and Vibrio parahaemolyticus without changing the smell, taste or appearance of oysters [19].

According to [20], when assessing the effectiveness of radiation treatment of chilled fish, it is necessary to take into account physicochemical changes (for example, oxidative decomposition) that cause product spoilage. Thus, irradiation with doses above 4.5 kGy can lead to oxidative damage to fish, which is confirmed by the results of studies [21-23], to autooxidative changes leading to the formation of typical oxidation products, and non-oxidative radiological changes [24].

The ongoing breakdown of protein fractions, including essential amino acids and sulfur-containing amino acids, reduces the nutritional value of irradiated products, according to [25].

From the point of view of radiation safety for humans, the information obtained by the American authors [26] about the possible risk for marine biota and consumers of seafood after the accident at the Fukushima nuclear power plant is interesting. The dose from radionuclides found in migrating fish from the scene of the accident is two orders of magnitude lower than people usually get from naturally occurring radionuclides in many foods when undergoing medical procedures, air travel or other background sources. At the same time, the risk of developing cancer can lead to two additional cancer deaths per 10,000,000 people, which is a negligible amount.

At the same time, it is necessary to take into account the results of studies [24, 27], which state that insignificant amounts of toxic compounds (acetaldehyde, acetone, formaldehyde, formic acid, benzene, toluene, hydrogen sulfide, dimethyldisulfide and etc.), but which cannot cause a direct toxic effect on the human body.
It is possible to establish the fact of processing by ionizing radiation only as a result of instrumental studies. It is important for detecting the fact of exposure that the radiation-induced electron paramagnetic resonance (EPR) signal can be detected after 60 days [28].

Hypothetically, it can be assumed that imported food products can be treated with ionizing radiation.

Based on this, the purpose of our research is to identify and study the safety of imported chilled fish sold on the consumer market of the Sverdlovsk Region, according to the requirements of the EAEU TR 040/2016 “On the safety of fish and fish products”.

2. Research materials and methods
The study was conducted on samples of chilled imported and packaged in consumer cardboard packaging rainbow trout (Salmo irideus). The study of labeling on consumer packaging was carried out in accordance with the requirements of regulatory documentation.

The identification of rainbow trout to establish the fact of irradiation or non-irradiation was carried out using bone tissue (OCT) samples by EPR according to the requirements of GOST R 52529-2006 “Meat and meat products. The electron paramagnetic resonance method for detecting radiation-processed meat and meat products containing bone tissue” (due to the lack of regulatory documentation for fish research) according to the automated software for the X-band EPR spectrometer of the Labrador Expert brand. The studies were carried out at a microwave frequency of 9200 MHz in the magnetic field range from 3200 to 3400 G.

Evaluation of the quality of chilled fish was carried out according to organoleptic indicators (appearance, smell, color, texture), freshness indicators and microbiological indicators according to generally accepted standard methods during storage.

The research results were processed by the method of variation statistics using the Student coefficient.

3. Research results
The information that was applied to consumer packaging, in which rainbow chilled trout of imported production was packed, met the requirements of GOST R 51074-2003 “Food products. Information for the consumer. General requirements”.

When studying trout OCT prepared according to the method of sample preparation according to GOST R 52529-2006, using the EPR method, the appearance of EPR signals with a peak amplitude of $(1.83 \pm 0.02) \times 10^{-5}$ rel. units (figure 1), which allows us to conclude that the fish were previously treated with ionizing radiation ($p \leq 0.05$).

![Figure 1. Spectrum of imported trout OCT (g-factor 2.0032±0.0004).](image-url)
The polynomial EPR model of the OCT spectrum of imported trout is represented by the equation:

\[ Y = 3 \times 10^{12}X^5 - 5 \times 10^8X^4 + 1.037X^2 + 1700X + 1 \times 10^6. \]  (1)

After the fact of exposure was established, an additional check was carried out to ensure compliance with the labelling requirements in accordance with the requirements of GOST 33800–2016 “Irradiated food products. General labelling requirements”. It was established that regarding the need to inform consumers about the processing of food products by radiation, violations of the requirements of GOST 33800–2016 were made and there was no information on the package on the package that should be reported to consumers. At the same time, the application of the Radura-logo (figure 2) is compulsory abroad, unlike in Russia, where the use of the international symbol for food product exposure is voluntary.

![Figure 2. Radura-logo.](image)

Organoleptic evaluation was carried out in accordance with GOST 7631-2008 “Fish, non-fish objects and products from them. Methods for determining organoleptic and physical indicators”. The appearance and color of the products was determined by external inspection of whole fish; the color of muscle tissue - in a cross section in the fleshiest part; the presence of subcutaneous yellowing - after skin removal; determination of consistency by pressing on a transverse section; smell - on the surface and in the thickness of the fish, in the gills.

As a result of an organoleptic assessment of imported rainbow trout, it was found that trout samples after 0, 10 and 15 days of storage belong to samples that fully correspond to fresh chilled fish according to GOST 814-96 “Chilled fish. Specifications”: the surface is wet, covered with light mucus; gills pink-red, odorless spoilage; the scales are not knocked down, the skin color is silver with black spots and a light olive back; the consistency is elastic; when pressed, it quickly recovers; the color of muscle tissue is pinkish-white, fat is white; the smell characteristic of fresh fish.

The indicators of freshness are investigated. The acid number and peroxide number were within normal limits, which indicates the absence of hydrolysis and oxidative damage to fish fat during storage for up to 15 days. The acid number was at the level of 0.7-1.1 mg KOH/g of fat and the peroxide value was 0.9-1.5 mmol of active oxygen/kg of fat.

Microbiological indicators correspond to the permissible level during storage up to 10 days of storage (according to GOST 814-96) and up to 15 days of storage (excess of storage by 50%) (table 1).

| Table 1. Microbiological parameters of chilled trout samples after 10 and 15 days of storage. |
|--------------------------------------------------|---------------------------------|----------------|-----------------------------------|
| KMAFAnM, no more, CFU/g | BGKP (coliforms), not allowed in the mass of the product, g | S. aureus, not allowed in the mass of the product, g | V. parahaemoliticus, no more, CFU / g |
| 10^5 | 0.001 | 0.01 | 100 |
| After 10 days of storage | Not found | Not found | Not found |
| After 15 days of storage | Not found | Not found | Not found |
The results obtained prove the high efficiency of radiation treatment of chilled fish.

4. Conclusion
Based on the studies, the possibility of identifying previously irradiated fresh fish is proved. The use of ionizing radiation for the processing of fresh fish ensures its preservation, compliance with the requirements of TR EAEU 040/2016 "On the safety of fish and fish products" and the extension of shelf life.

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