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PRESERVATION OF RAPANA MEAT BY THE IRRADIATION TECHNOLOGY

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Abstract. The article considers the technology of maturing preserves from the meat of the Black Sea gastropod mollusc *Rapana thomasiana* using irradiation technologies. The methods of improving the technology of processing rapana meat have been studied in order to ensure long-term storage of the finished product without using artificial preservatives. The technology is based on the preliminary preparation of the semi-finished product, which includes defrosting, sorting, cutting, washing, inspection, portioning, blanching, and cooling. It has been studied how different methods of preprocessing the raw material affect the mechanostructural properties of rapana preserves. Blanching the meat of rapana has proved practical. Acetic acid has been shown to increase the sensitivity of rapana muscle tissue to microwaves. It has been found effective to soften rapana muscle tissue by marinating with acetic acid and by using microwave irradiation in various doses (2 to 10 kGy) for 60 s. The choice of the recommended dose of 2 kGy has been substantiated. It has been established that after microwave processing, the sensory properties of the finished product do not change. The system of microwave processing of preserved meat to soften its inhomogeneous structure has been described. The shift of kinetic energy in the electronic field using thin targets to form the required radiation field of different sizes has been used. This has allowed influencing the inhomogeneous structure of the raw material. It has been proved that after microwave irradiation with the dose 2 kGy, the preserved rapana meat is microbiologically safe and can be stored for 90 days at 4±2°C. The technological scheme of making preserves from rapana meat using PWP has been provided. The studies indicate that using the irradiation technology is practical, as it ensures the maturation of low-maturing aquatic organisms, extends the shelf life of food, guarantees safety and high quality.

Keywords: irradiation technologies, microwave radiation, food industry, rapana meat, preserves.

Introduction. Formulation of the problem

The research relates to the food industry and considers the improvement of the technology of preserving the meat of the Black Sea gastropod *Rapana thomasiana* by applying irradiation technologies.

Molluscs, as a source of protein for human nutrition, are becoming increasingly important in the global aquatic fishery. Reducing fish catch and shifting consumers' focus of interest toward low-calorie, highly nutritious, healthy, and wholesome food, have transformed the seafood market into one of the fastest-growing, especially in the delicacies segment [1]. However, the producers' desire to increase profits and production volumes through the use of outdated technologies and equipment, cheap raw materials,

artificial food additives, wholly or partly replacing expensive and high-quality raw materials with substitutes, reduces the biological value of food, its quality and safety.

Nowadays the decline in stocks of marine raw materials has led to a sharp rise in production costs and instability in the world market. Therefore, in Ukraine, the mass share of local catch and its processing using domestic technologies should be increased. Fig. 1 shows the characteristics of the levels of self-sufficiency in the main types of food in Ukraine. Fish and seafood have the lowest percentage of self-sufficiency – 24.1% (Fig. 1). In this regard, the search for new seafood technologies and the improvement of traditional ones becomes especially important.

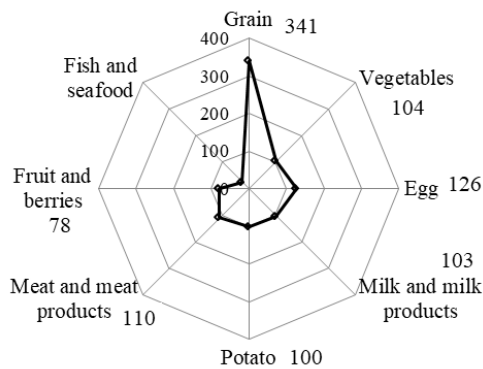


Fig. 1. Levels of self-sufficiency in basic foods in Ukraine, % [2]

Analysis of recent research and publications

Declining stocks of marine fish species have necessitated the development of new technologies for preserved food from non-traditional raw materials such as molluscs, including rapana [1].

The Black Sea is a natural resource base of the gastropod mollusc *Rapana thomasiana*. Its meat is of high biological value due to the protein content, but has a thick consistency, so is used mainly to manufacture culinary products [3].

One of the promising methods of ensuring and maintaining the quality and safety of aquatic organisms is the technology of preserves, which are valuable food articles. The peculiar features of this technology involve the use of salt, sugar, marinades, various sauces or fillings, and hermetically sealed jars without the use of sterilisation. The following preservatives can be added to preserves: sodium benzoate, potassium sorbate, organic acids. This technology ensures maximum preservation of the biological value of proteins and the effectiveness of lipids and vitamins, to a large extent, close to natural raw materials. Leakproofness of the packaging keeps harmful microbial flora from entering these products, which ensures the safety of the finished product. Preserves are suitable for direct human consumption without any additional cooking or other processing. Usually the shelf life of these products is limited to 14–30 days.

The theoretical foundations of the preserves technology were laid by I. Levanidov, L. Minder, V. Shenderyuk [4-10] who tested various ways of preservation while developing methods of obtaining low-salt fish products. The theoretical principles were then developed in the studies by N. Voskresensky, N. Kupina, O. Mezenova, T. Slutskaya, B. Nekhamkina, V. Golenkova [4,6-9,11].

The process of maturing preserves for higher nutritional value is determined by a combination of factors, among which the activity of muscle enzymes and the high-fat content are of primary importance. The maximum activeness of these enzymes occurs at the pH value 4.5 [12].

Traditionally, fat fish with high growth rates is used in preserves production due to the high activity of their own muscle tissue enzymes, cathepsins. But the production of preserves from slow-growing raw materials, (which include rapana) requires supplementing them with various food additives, lactic acid bacteria [14], and complex mixtures for maturity, such as phosphate or phosphate-free ones like Garnelen Coma Con® and Stabil Crustasia Marin®. Such additives are also used to ensure a juicy consistency [13]. The use of microwave energy also promotes the maturing of fish preserves [15]. In order to improve the organoleptic quality of the finished preserves, the blanching method is used [16].

Preservation technologies belong to the most environmentally friendly and efficient methods of processing seafood into ready-to-eat foods. The main problem of their safety is the natural contamination of raw materials by microorganisms. Besides, the high moisture content in the meat of aquatic organisms limits the shelf life of finished products. The manufacturer is able to determine the shelf life of food. For preserves from seafood without preservatives, it is 14 days at $4\pm 2^{\circ}\text{C}$. To date, various ways to increase their storage stability have been developed and tested, including reducing the moisture content in the finished product by absorbing it with hygroscopic additives from dried vegetables [3].

The latest promising achievements in these technologies consist in using the energy of picowave electron radiation (picowave processing, or PWP) to suppress the activity of the microflora and increase storage stability under standard conditions for retail chains. The Institute of Nuclear Research of the National Academy of Sciences of Ukraine (INR NAS of Ukraine) has created a technology of low-salt sea fish preserves that involves low-temperature pasteurisation using PWP. The technology allows them to be stored for more than 6 months at $4\pm 2^{\circ}\text{C}$ without preservatives. The positive results of using picowave radiation energy in previous studies make the technology of high-quality and safe rapana preserves with a long shelf life highly attractive.

The study is based on the previous experience of using picowave energy to suppress the microflora of fish preserves at $12\text{--}22^{\circ}\text{C}$ [17]. It is an alternative to conventional methods of increasing the shelf life of preserves, based on adding artificial chemicals (preservatives, stabilisers, and other food additives), which, although they solve, to some extent, the problem of the storage of these products, but pose a threat to consumers' health. This stimulated the development radiation technologies used in food production and their worldwide spread.

The mechanisms of energy transfer of ionising radiation into food have long been studied by leading research organisations, IAEA scientific units (International Atomic Energy Agency), and National Research Centres [18,19]. Irradiation technologies applied in food processing with limited parameters

were proved to be efficient and safe for the human body. On this basis, the International Code of Laws (Codex Alimentarius) on irradiation, distribution, and consumption of irradiated products was created [20]. The most comprehensive information needed to develop these technologies is published in the fundamental work by A. Nechaeva [21]. The authors' determination on the use of radiation technology is based on the decision of the Joint Committee of Experts of the Food and Agriculture Organisation, the United Nations, the International Atomic Energy Agency, and the World Health Organisation on the

safety of irradiated products, established in November 1980, who concluded that any food product was acceptable if irradiated with a total average dose of 10 kGy [22].

To provide a scientific basis for the selection of PWP parameters, it is important to investigate first the impact of the concomitant effects. It is acknowledged from theoretical studies that these effects include radiolysis of water, which produces hydroxyl radicals, hydrogen peroxide, higher hydroxyl radicals, nitrogen, and other active radicals (Table 1).

Table 1 – Radiolysis products found in organic food raw materials high in moisture [23]

Parameters	Radiolysis products			
	Hydroxyl radicals $\cdot\text{OH}$ ($\cdot\text{O}$)	Hydrogen peroxides H_2O_2	Higher hydroxyl radicals $\text{H}\cdot\text{O}_2$	Nitrogen N_2^* N_2^+
Radiation chemical yield, G (mol./100eV)	3.0 for pH=0.4 2.8 for pH=7 3.0 for pH=13($\cdot\text{O}$)	0.8 for pH=0.4 0.75 for pH=7	0.02 for pH=0.4	0.8

These processes are determined by the composition of the raw material irradiated and by the radiation parameters: the power of the exposure dose, and the actual value of the absorbed radiation energy [21,23].

It is known from the theoretical principles of radiation chemistry that the accumulation of radiolysis products does not depend on the energy of radiation [21]. In PWP, the moisture that is more than 70% in seafood meat is exposed to radiolysis in the first place. Compounds formed by molecule disruption and ionisation are highly reactive, with disrupted ionised molecules forming free radicals and molecular products.

The specific patterns have only been established for maturing marine fish species [24,25]. These patterns show the effect of PWP on the processes of maturing preserves and improving their safety, and require further study on poorly-maturing raw rapana materials.

Research purpose and objectives. The purpose of the work is to elaborate the technology of rapana meat preserves that allows manufacturing mature preserves with organoleptic characteristics acceptable to consumers and ensures safety of finished products during long-term storage without using artificial preservatives.

The objectives:

- to study the effect of different doses of PWP on the change in the active acidity of rapana meat;
- to develop a method of softening the inhomogeneous structure of rapana by applying PWP;
- to determine the features of the impact of radiation on raw materials from rapana depending on the type of its preprocessing and PWP conditions;
- to determine the microbiological safety and recommended storage conditions for preserves from rapana;
- to develop a technological framework of preserves from rapana meat with the use of PWP to ensure the quality and safety of the products ready for consumption.

Research materials and methods

The material used for the study was the meat of the gastropod mollusc *Rapana thomasiana*, caught in May off the Black Sea coast of Odessa, Ukraine.

After being caught, rapana was cleared from silt, sand, algae, etc., and then sorted. After sorting, live molluscs with a total weight of 110 ± 30 g, aged 3–5 years, with the shell height 75 ± 7 mm and shell width 60 ± 5 mm, were frozen at -30°C until the temperature of the raw material was -18°C , and stored at this temperature for 2 months.

To manufacture preserves, the rapana was defrosted for 60 min at room temperature ($15\pm 2^\circ\text{C}$), cut, with the entrails removed, washed in water at $t=15\pm 5^\circ\text{C}$, inspected, portioned into 15×20 mm pieces, blanched at $t=98\pm 2^\circ\text{C}$ for 20–30 s, and cooled to $t=45\pm 2^\circ\text{C}$.

To study how preprocessing with acetic acid (CH_3COOH , $\text{C}_2\text{H}_4\text{O}_2$, food supplement E260) and table salt (NaCl, sodium chloride) affected the consistency of rapana, the first group of the samples was processed with an aqueous solution of acetic acid in the concentrations 0.5, 1.0, 1.5, and 3.0%, the second one with dry table salt in the amount 5% of the sample weight, and the third group, in order to compare and determine the more applicable technique of raw materials preprocessing, with marinade containing 5% of salt, 1.5% of sugar, 2% of spices, 1.5% of acetic acid, and up to 100% of water. No processing was performed on the reference sample. Then the samples were packed in plastic jars weighing 200 g, closed tight, labelled, and left for 48 hours at $4\pm 2^\circ\text{C}$ until ready. Samples for research were stored at $t=4\pm 2^\circ\text{C}$ and relative humidity not more than 75%.

The next step was the picowave processing of the prepared rapana samples and the reference to obtain the total average dose of 2.5 and 10 kGy. The irradiation time determined experimentally ranged 30 to 300 s. The optimal processing time was 60 s at the dose of 2 kGy, at which the sensory properties

remained stable, the structure became homogeneous, and the consistency was soft. All studies were performed at $t=20\pm 2^{\circ}\text{C}$, and the relative humidity was not more than 75%.

Sensory evaluation of the quality of rapana preserves was performed according to our scale of evaluation shown in Table 2.

The scale, according to which specific parameters of sensory evaluation corresponded to the penetration index (Q), was developed to assess the impact of different methods of preparing preserves on the consistency of rapana meat (Table 3).

The consistency of the rapana meat in the preserves was examined on an SC 900 Soil

Compaction Meter (penetrometer) from Spectrum Technologies, USA.

The dosimetry was performed with a colour visual indicator TSVID (LLC *LASSO-tsestr*, Russia) by pre-measuring the intensity of the radiation field per unit surface of the samples with the subsequent correlation of this dose to its spectral composition. In order to control the integrated absorbed dose, an individual colour visual indicator TSVID was attached to each sample. The total measurement error did not exceed 10%, which satisfies the standards for food irradiation.

The active acidity of rapana meat was determined by the potentiometric method on a membrane pH meter NO 83141 HANNA (HANNA Instruments Deutschland GmbH, Germany).

Table 2 – Evaluation of the sensory quality parameters of rapana meat preserves

Quality parameters	Score				
	5	4	3	2	1
Appearance	Intact pieces of the same size and shape; distinctly shaped; the filling remains evenly distributed, covering the surface of the product	Pieces of different shapes and sizes; distinctly shaped; the filling remains evenly distributed, covering the surface of the product	Pieces of different shapes and sizes; indistinct shape; the filling does not cover the surface of the product	Pieces of different shapes and sizes; a lot of small pieces; the filling is unevenly distributed	Pieces do not have a distinct shape and edges; the filling does not cover the surface of the product
Colour	Bright, homogeneous	Bright, homogeneous	Bright, inhomogeneous	Dark, inhomogeneous	Dark, inhomogeneous
Smell	Pleasant, harmonious, inherent, without extraneous odours	Pleasant, characteristic	Foreign odours are present	Uncharacteristic	Unpleasant, uncharacteristic
Texture	Tender, homogeneous	Mild, elastic, homogeneous	Thick, inhomogeneous	Tough, inhomogeneous	Smearred, inhomogeneous
Consistency	Soft, juicy; the product is easily bitten, forms a homogeneous mass when chewed	Soft; the product is safe for teeth; however, when chewed, elastic particles remain	Malleable, but very thick	Thick, tough, requires considerable efforts to bite	Very soft, smears, envelops the mouth, makes it difficult to swallow
Taste	Pleasant, harmonious, characteristic, without extraneous taste	Pleasant, characteristic	No extraneous taste	Uncharacteristic	Unpleasant, uncharacteristic

Table 3 – Scale of correspondence of the penetration index to the points of sensory evaluation of rapana meat

Consistency	Penetration index, Q, kPa	Sensory evaluation, score
Thick, tough, requires considerable efforts to bite	More than 6.41	1
Thick, retains deformation, difficult to bite	6.40–5.81	2
Malleable, but very thick	5.80–5.41	3
Soft; the product is safe for teeth; however, when chewed, elastic particles remain	5.40–4.41	4
Soft, juicy; the product bites away well, forms a homogeneous mass when chewed	4.40–2.90	5
Very soft, smears, envelops the mouth, is difficult to swallow	2.89 and lower	0

The quality and safety of rapana meat preserves were determined in accordance with European Parliament and Council Regulation No. 178/2002 [26] and EU Commission Regulation No. 2073/2005 [27], namely: the quantity of mesophilic aerobic and facultative anaerobic microorganisms (QMAFAnM) was performed by counting colonies that grow on a solid nutrient medium after incubation at 30°C according to ISO 4833-2006; *E. coli* bacteria according to ISO 16649-1:2018; *Staphylococcus aureus* according to ISO 6888-1:1999; sulphite-reducing clostridia according to ISO 15213:2003; pathogenic microorganisms, including those of the genus *Salmonella*, in accordance with ISO 6579-1:2017. As a reference, preserves from the meat of the gastropod *Rapana thomasi*, made without preprocessing of the raw materials with salt, vinegar, or marinade, blanching, and PWP, were used.

Results of the research and their discussion

To compare the different technologies of making preserves from rapana meat, the effectiveness of softening its muscle tissue by marinating with different concentrations of acetic acid added was previously tested, and PWP was used the doses 2 to 10 kGy for 60 s.

The experimentally obtained dependences of softening of rapana tissues under the influence of acetic acid in the concentrations 0.5, 1, 1.5, and 3% are shown in Fig. 2 [28]. The dynamics of changes in the consistency of rapana meat remained the same with almost all acetic acid concentrations, but the most significant softening of the consistency was obtained under the influence of 3% acetic acid solution after 12 hours of processing. It reaches the optimal sensory and mechanostructural values after 28–38 hours. Further exposure to acetic acid leads to deterioration of the sensory characteristics, and rapana meat acquires a smeared consistency.

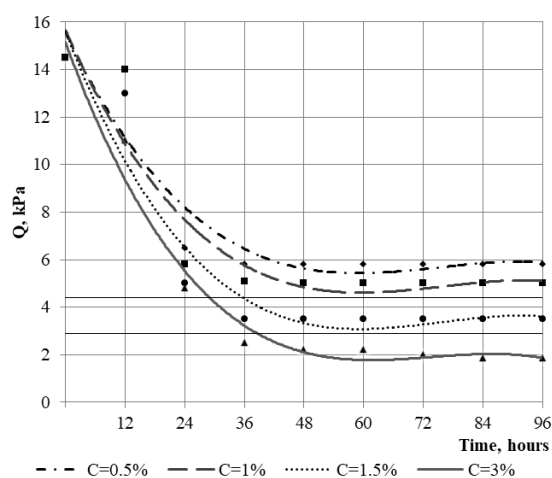


Fig. 2. Dependence of the consistency of rapana muscle tissue on the acetic acid concentration and period of exposure

As can be seen from Fig. 2, with 1.5% of vinegar added during marination, the penetration rate is within the range 2.9–4.4 kPa and still remains the same after 38 hours, in contrast to adding 3% vinegar, which corresponds to the highest score of the organoleptic scale. Therefore, the lowest acetic acid concentration that can be used in the technology of rapana meat preserves to soften the consistency was 1.5%.

Even though reducing the concentration of acetic acid solutions to 1.0 and 0.5% leads to a softer consistency of the muscle tissue of rapana, at any exposure, the sensory quality indicators do not reach acceptable values. This means that traditional methods involving using organic acid to soften the muscle tissue consistency in molluscs can be applied but take a considerable time on this technological stage and cannot ensure stable product quality characteristics of this raw material.

The specific features of this raw material type are the densely arranged fibres of its smooth muscles, which complicates the processing of this mollusc. Previous experiments have shown that dense rapana tissues undergo significant destruction when absorb high doses of radiation (up to 10 kGy) during PWP. That is why the possibility of using the energy of picowave irradiation to soften the muscle tissue of rapana has been investigated.

The preservation technology is accompanied by the activation of rapana's own muscle tissue enzymes and changes in the rate of active acidity during maturation. Fig. 3 shows the results of studying the active acidity in the samples treated with PWP doses of 2 and 10 kGy and preprocessed with 5% of salt, 1.5% of acetic acid solution, 5% of marinade containing salt, 1.5% of sugar, 2% of spices, 1.5% of acetic acid, and up to 100% of water, and in the reference sample without prior processing using food additives.

Research has shown that PWP in the doses 2 and 10 kGy, with saline solution added to raw rapana meat, does not change the acidity, which corresponds to the value of this parameter in the reference sample. The addition of salt and pre-blanching of rapana changes the acidity, increasing its level from 5 to 9.

The PWP of rapana meat differs significantly in an acidic environment. This means that the acids used act as sensitizers, i.e. increase the sensitivity of the irradiated environment to the action of radiant energy. The addition of acetic acid changes the initial acidity of the irradiated medium, but subsequent peak processing does not affect this figure. When irradiated in the marinade, due to the formation of moisture radiolysis products, compounds are formed that acquire a sensitizing effect and increase the sensitivity of the medium to radiation processing. This allows obtaining the required consistency of preserves at the PWP dose 2 kGy.

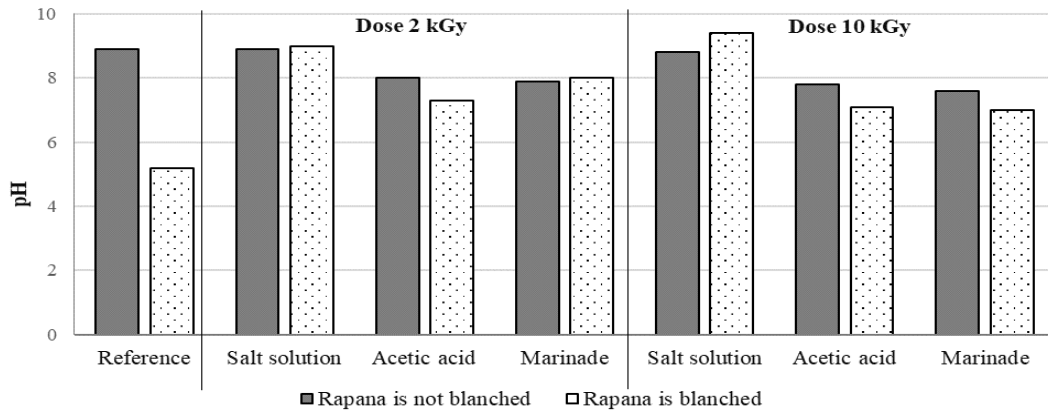


Fig. 3. Dependence of acid accumulation in rapana muscle tissue on the peak dose of energy intake absorbed from food additives

The sensory evaluation has determined the high quality of preserves made using PWP, which indicates the advantages of using PWP energy in the preservation technology.

Rapana tissues have an inhomogeneous structure, the denser layers of which require higher doses of radiation. Processing of the bulk of the raw material at a dose of more than 2 kGy makes it difficult to obtain the desired technological effect due to the so-called “electronic” taste. Therefore, the task was to develop a radiation technology, which should solve two tasks simultaneously: destroying the dense component of the raw materials to obtain the required soft consistency, and pasteurising the finished product by forming a specific structure of the radiation field of the material. Preliminary estimates made according to the recommendations [29] showed that this could be achieved by forming a complex radiation field (Fig. 4).

The irradiation field should be formed so that the absorbed dose in the near-surface layer (1–4 mm) is 10 times higher than the dose absorbed in the total volume

of the sample. This is easy to achieve if you pre-irradiate the material with low-energy electrons of 0.4–0.5 MeV with a high exposure dose rate of not more than 2 kGy. But this option is not suitable for further use in industrial production due to its complexity, so it is advisable to conduct experiments with a complex structure of the radiation field obtained by superposition of radiation of different energies. The original part of the implementation of this solution is the purposeful modification of a monochromatic electron beam of 4–5 MeV into electron fluxes of different energies (from 0.5 to 5 MeV).

For this purpose, the well-known effect of electron scattering on thin targets was used [30]. When passing in the electric field of atoms of the scatter material, the electrons lose their kinetic energy, and the emittance of the beam increases significantly. The transformation in kinetic energy in the electron field using thin targets made of aluminium with a thickness of 1 mm has been studied.

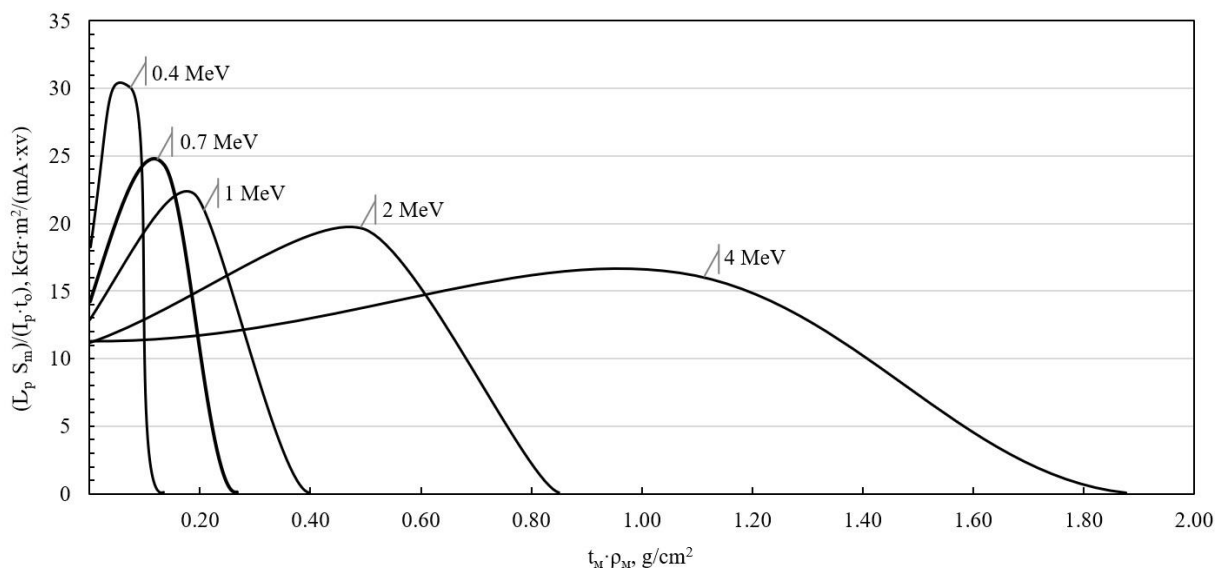


Fig. 4. Technical characteristics of the combined irradiation field with various electron beam energies for technological processing of rapana meat

It has been established that each of these diffusers increases the angular divergence of the beam with the initial diameter 3–4 cm by 16 degrees. Sequential installation of different numbers of such screens allows changing the emittance of the beam in a wide range and obtaining radiation fields of different sizes. Typically, there is also a change in the energy structure of the beam: its composition increases the content of low-energy electrons.

Technical measures of changing additionally the angular characteristics of a beam of falling electrons have been developed. Calculations have shown that this method is perfectly suitable for the formation of the irradiation field, where the number of electrons falling on the surface of the samples at large angles significantly exceeds the number of electrons normally entering the sample material. This is achieved by using reflectors, which redirect the trajectory of the electrons at large angles to the surface of the irradiated samples. The obtained radiation field due to the absorbed energy will be close to the established requirements [31].

Subsequent studies have confirmed that the combined use of both of the above effects has solved the problem. Its practical implementation provides the resulting effect of radiation energy absorption, which is quite close to the characteristics shown in Fig. 4. The technical solution to this problem is a special system of forming a beam of the desired configuration, consisting of a set of diffusers (1) and reflectors (2) (Fig. 5).

The prepared raw materials were appropriately placed in plastic jars, the necessary additives were introduced, preserves were formed and sealed. Preserve jars were packed in tablets, hung on a conveyor to move to the reaction chamber for radiation processing [32], where they were processed with the generated electron flux in different doses (Fig. 5), and immediately rapid measurement was performed and the main target process parameter optimised (penetration rate (Q , kPa) – the degree of change in the consistency of the muscle tissue of the rapana).

The dynamics of changes in the rapana meat consistency under the action of the stream of accelerated electrons in various doses is shown in Fig. 6.

When preprocessing pieces of rapana muscle tissue in the marinade and acetic acid separately, the most favourable effect of irradiation on the consistency is with the dose 2 kGy for 60 s. As a result of such exposure, the rapana muscle tissue becomes tender forming a homogeneous mass when chewed. Exposure to higher (5–10 kGy) doses leads to excessive softening of the muscle tissue of the rapana.

The results collected confirm our previous findings [33], but in order to improve the organoleptic quality of the finished preserves, a blanching process was added to the technology.

Blanching for 30 s at $t=98\pm 2^\circ\text{C}$ and subsequent irradiation facilitate the process of softening the consistency of rapana muscle tissue at all doses of electron beam radiation without prior processing in the marinade, acetic acid, and salt. However, a combination of blanching, processing with salt, acetic acid, marinade, and subsequent peak irradiation with the doses 5 and 10 kGy leads to excessive softening of muscle tissue, while the use of the minimum dose 2 kGy under similar conditions provides high sensory quality of the samples (Fig. 6).

Thus, comparison of the results of sensory evaluation and the penetration index (Q) indicates that in order to change the structure of rapana muscle tissue and obtain a high organoleptic score, it would be practical to use a combined technology: blanching and marinating rapana meat, packaging, sealing, and processing with accelerated electrons with the minimum dose 2 kGy.

So, it has been established that high mechanostructural quality of rapana meat preserves can be achieved by defrosting raw materials, sorting, cutting, cleaning, inspection, portioning, blanching, cooling, processing with acetic acid or marinade containing 1.5% of acetic acid, 5% of salt, 1.5% of sugar, 2% of spices, 90% of water, and a subsequent PWP dose of 2 kGy for 60 s.

An essential component of the technology is the safety of the product in terms of the microbiological characteristics. The results of these studies are given in Table 3.

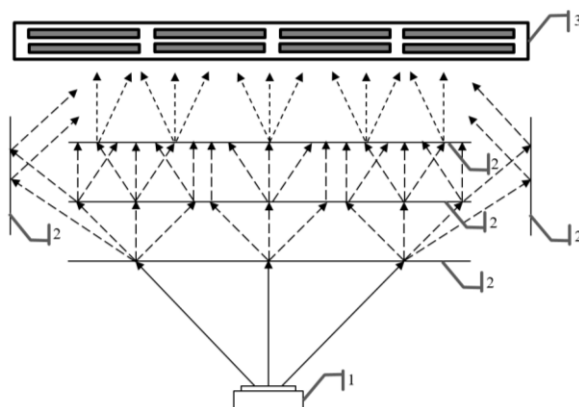


Fig. 5. Scheme of the system of picowave processing of preserves from rapana: 1 – radiation source; 2 – diffusing screens; 3 – samples of preserves from rapana meat

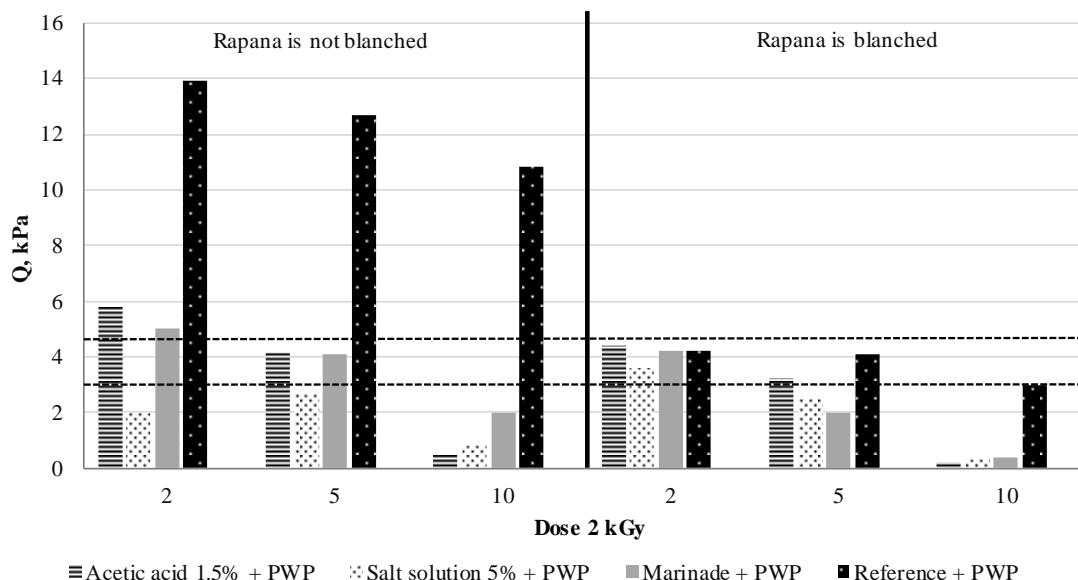


Fig. 6. Changes in the consistency of rapana muscle tissue preserves depending on the dosage of PWP and the method of preprocessing the semi-finished product

Table 3 – Changes in the microbiological parameters of rapana meat during storage after different types of processing (n=5, p≥0.95)

Parameters	Quantity of mesophilic aerobic and facultative anaerobic microorganisms, CFU in 1 g							Bacteria of the <i>E. coli</i> group, in 0.01 g	<i>Staphylococcus aureus</i> in 0.01 g	Sulphite-reducing clostridia in 0.01 g	Pathogenic m/o, including the genus <i>Salmonella</i> , in 25.0 g
	Acceptable levels	not more than $1 \cdot 10^5$									
Shelf life, days	0	10	20	30	60	90	0–90				
Content, CFU in 1 g of rapana meat	R	$0.51 \cdot 10^3$	$0.36 \cdot 10^5$	$1.76 \cdot 10^5$	–	–	–	not found	not found	not found	not found
	S	$0.15 \cdot 10^3$	$0.51 \cdot 10^5$	$0.68 \cdot 10^5$	–	–	–				
	A	$0.32 \cdot 10^2$	$0.43 \cdot 10^4$	$0.24 \cdot 10^5$	–	–	–				
	M	$0.43 \cdot 10^2$	$1.51 \cdot 10^4$	$0.63 \cdot 10^5$	–	–	–				
	Sc	$0.48 \cdot 10^2$	$8.49 \cdot 10^4$	$0.56 \cdot 10^5$	–	–	–				
PWP	$0.03 \cdot 10^2$	$0.09 \cdot 10^2$	$0.09 \cdot 10^2$	$0.13 \cdot 10^2$	$0.31 \cdot 10^2$	$0.78 \cdot 10^2$					

*R – reference without prior processing of raw materials; preprocessing of raw materials: S – processing with salt solution; A – processing with acetic acid; M – marination; Sc – scalding; PWP – picowave processing (2 kGy for 60 s)

Analysis of changes in the microbiological parameters of rapana meat after different types of processing shows a positive impact of all technological operations on the safety of the finished product. PWP has shown the greatest efficiency in slowing down the development of mesophilic aerobic and facultative anaerobic microorganisms. Pathogenic microflora was detected in none of the studies.

The investigated range of picowave irradiation doses significantly exceeds the minimum level sufficient for complete suppression of pathogenic microflora and guarantees a long shelf life of preserves

from rapana meat at the storage temperature $4 \pm 2^\circ\text{C}$ for 90 days.

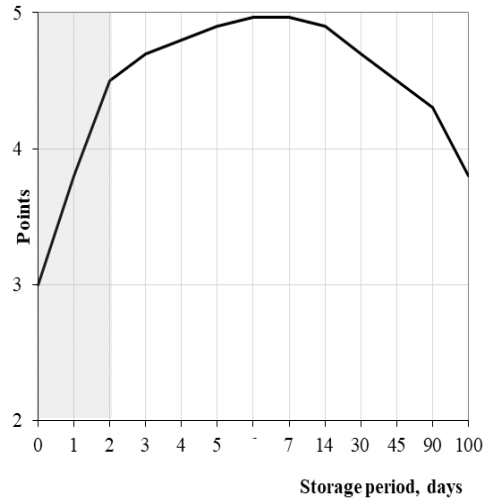
The results obtained are consistent with those of the previous studies [34-36] and indicate how practical it is to use PWP in rapana meat preservation technology to modify the texture of raw materials, regulate the product's maturing, and ensure its safety by the microbiological parameters.

The quality and safety characteristics of rapana preserves were studied within a 100-day period at the storage temperature $4 \pm 2^\circ\text{C}$. Signs of maturing of the product (tender homogeneous texture, juicy consistency of the meat, harmonious flavour and

aroma) were defined in the developed preserves as soon as after 2 days of storage. Characteristics of the changes in the sensory quality parameters of the preserves are shown in Fig. 7 in points.

The analysis shows that the highest organoleptic quality score (4.5–5 points) was observed from the 2nd to the 45th day of storage. After 90 days, there was a deterioration of the aromatic properties, and the first signs of over-maturing of the preserves were detected.

A technological scheme for the production of preserves from rapana meat using picowave processing has been developed. Fig. 8 shows a simplified technological scheme for the production of preserves with accelerated maturing and pasteurisation by picowave radiation energy. The following technological scheme has been repeatedly tested on the basis of the apparatus for PWP treatment of food products, which was created in the Institute of Nuclear Research of the National Academy of Sciences of Ukraine, and the results of the research have been published in a number of scientific papers [32,37,38]. For the production of preserves from rapana, the apparatus was supplemented with devices and applications for preparation of raw materials and batch canning of preserves. The scheme of picowave processing of preserves is traditional for the radiation apparatus of the Institute of Nuclear Research [38], but it is streamlined to obtain the radiation field distribution described above.



* the period for maturing of the preserves within 2 days is highlighted

Fig. 7. Changes in the sensory quality parameters during storage

According to the scheme shown in Fig. 8, an experimental batch of preserves has been produced from rapana meat and its safety has been studied in accordance with the regulatory documents effective in Ukraine.

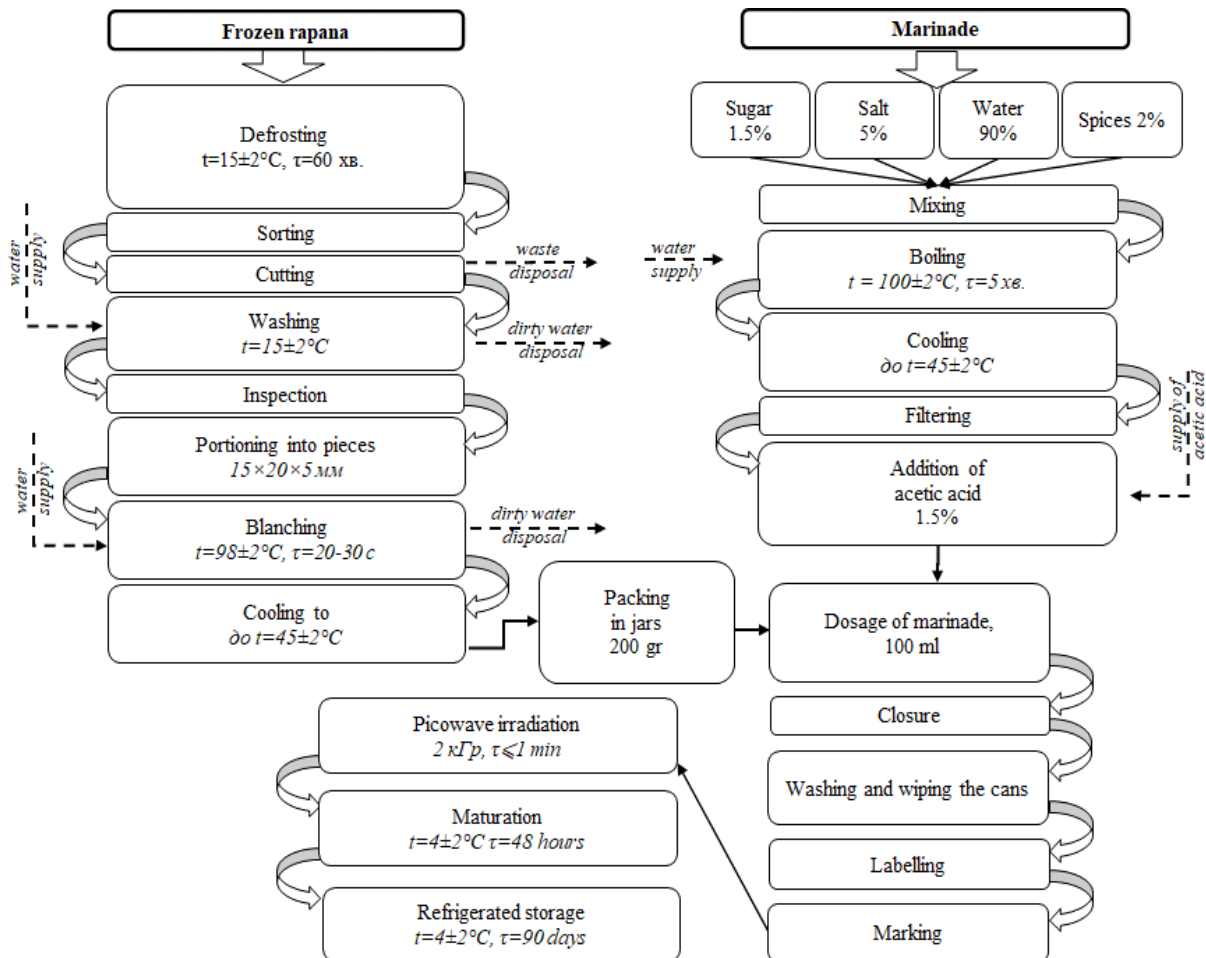


Fig. 8. Technological scheme of production of preserves from rapana meat

Rapana preserves produced by this method are ready for consumption. They can be transported immediately to the retail network or stored in cold chambers at $4\pm 2^{\circ}\text{C}$ and not more than 75% relative humidity for 90 days from the date of manufacture.

As aquatic products, including rapana, are most susceptible to microbiological spoilage, irradiation technology is an alternative to current trends in extending the shelf life of foods. Therefore, the method of application of electrons accelerated to 4 MeV was chosen, when the interaction of electrons with organic systems is accompanied by numerous beneficial effects [24,25,39,40]. The use of electron energy results in significant technological benefits. These useful properties of irradiation technologies create the preconditions for the effective replacement of certain operations of traditional mollusc processing technologies to extend their shelf life.

Conclusion

1. The effect of PWP in 2 and 10 kGy doses on the change of active acidity has been investigated. The raw meat was blanched for 20–30 s at $t=98\pm 2^{\circ}\text{C}$ and preprocessed with 5% of salt, 1.5% of acetic acid solution, 5% of marinade containing salt, 1.5% of sugar, 2% of spices, 1.5% of acetic acid, and up to 100% of water, and the reference sample underwent no prior processing using food additives. It has been detected that blanching rapana meat and processing it with 5% salt solution increases the pH from 5 to 9 compared to the reference. The addition of acetic acid or marinade has proved to reduce the initial acidity of the irradiated medium, but a further increase in the dose of microwave processing to 10 kGy does not significantly affect this value. The use of marinade will enable the formation of the proper sensory characteristics of preserves from rapana, and the acids in its composition increase the sensitivity of the irradiating environment, so PWP of 2 kGy is a sufficient dosage.

2. The scheme of the system of microwave processing of preserves to soften their inhomogeneous structure has been described. The kinetic energy in the

electronic field using thin targets made of 1 mm thick aluminium has been changed to form the required radiation field of different sizes allowing us to influence the inhomogeneous structure of raw materials.

3. A comparative study of how PWP of raw materials and blanching and marinating them affects the mechanostuctural quality of rapana meat preserves has been conducted. It has been detected that the consistency of preserves from rapana muscle tissue changes depending on the dose of PWP and the method of preprocessing of the semi-finished product. High mechanostuctural and quality characteristics of preserves from rapana meat can be achieved by using blanching at $t=98\pm 2^{\circ}\text{C}$ for 20–30 s, and marinating it in a filling containing 1.5% of acetic acid, 5% of table salt, 1.5% of sugar, 2% of spices, and 90% of water and subsequent PWP for 60 s with the 2 kGy dosage. The result is a product of high organoleptic quality, with a harmonious flavour and consistency acceptable for consumers.

4. Analysis of changes in the microbiological parameters of rapana meat after different types of processing indicates positive effects of all technological operations on the safety of the finished product. Of all the methods studied, PWP has demonstrated the greatest efficiency in slowing down the development of mesophilic aerobic and facultative anaerobic microorganisms. Furthermore, none of the studies detected pathogenic microflora. With regard to the findings of the study, the guaranteed shelf life of preserves from rapana meat has been established to be 90 days at $4\pm 2^{\circ}\text{C}$ and relative humidity not more than 75%.

5. A technological scheme for the production of preserves from rapana meat using PWP has been developed.

Thus, radiation technology is an alternative to modern methods of shelf life extension of food without losing its nutritional value. It is more energy-efficient than thermal processing and safer for public health than the use of artificial preservatives.

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РАДІАЦІЙНА ТЕХНОЛОГІЯ ПРЕСЕРВІВ ІЗ М'ЯСА РАПАНИ

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Анотація. У статті розглянуто технологію дозрівання пресервів з м'яса чорноморського червоного моллюска *Rapana thomasiana* шляхом використання радіаційних технологій. Досліджено шляхи удосконалення технології переробки м'яса рапани для забезпечення тривалого терміну зберігання готового продукту без використання синтетичних консервантів. В основу технології покладено попередню підготовку напівфабрикату, що включає розморожування, сортування, розбирання, миття, інспекцію, порціонування, бланшування, охолодження. Досліджено вплив різних способів попередньої обробки сировини на структурно-механічні показники пресервів із м'яса рапани. Доведено доцільність застосування бланшування м'яса рапани. Встановлено ефективність застосування оцтової кислоти для підвищення чутливості м'язової тканини рапани до пікохвильової обробки. Показано ефективність розм'якшення м'язової тканини рапани шляхом маринування з додаванням оцтової кислоти та за рахунок використання пікохвильового опромінення дозами від 2 до 10 кГр протягом 60 с. Обґрунтовано вибір рекомендованої дози у 2 кГр. Встановлено, що після пікохвильової обробки органолептичні показники готового продукту не змінюються. Описано схему системи пікохвильової обробки пресервів для розм'якшення її гетерогенної структури. Використано зміну кінетичної енергії в електронному полі з використанням тонких мішеней для формування необхідного радіаційного поля різної площі, що дозволяє впливати на гетерогенну структуру сировини. Доведено мікробіологічну безпечність пресервів з м'яса рапани після пікохвильового опромінення дозою 2 кГр, що забезпечує їх зберігання протягом 90 діб за температури 4±2°C. Наведено технологічну схему виготовлення пресервів з м'яса рапани з використанням пікохвильової обробки. Проведені дослідження свідчать про доцільність використання радіаційних технологій для забезпечення дозрівання слабкодозріваючих гідробіонтів для подовження термінів зберігання харчового продукту гарантованої безпечності та високої якості.

Ключові слова: радіаційні технології, пікохвильове випромінювання, харчова промисловість, м'ясо рапани, пресерви.

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