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Functional and technological properties and nutritional value of jellyfish *Rhizostoma pulmo* (Macri, 1778)

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Abstract. Representatives of jelly plankton (in particular, scyphoid) are the underutilized resources in the Azov-Black Sea Basin. The wave nature of their reproduction has a powerful impact on the ecosystems of the two seas. Seasonal outbreaks of abundance cause an increasing pressure on the food supply of commercial aquatic organisms, a change in the structure and quality of fish catches, and a deterioration in recreational conditions in the resort areas of the Azov-Black Sea Basin. The importance of the search for a rational solution to the problem of processing *Rhizostoma pulmo* jellyfish can be explained by the specific features of their biochemical composition, presence of biologically active substances in the tissues of aquatic organisms, their low liquidity as raw stuff and seasonal resource availability. There are presented the data on the size-weight composition of *Rh. pulmo* caught in the Sea of Azov, the influence of various types of heat treatment (freezing, boiling, microwave treatment, enzymatic hydrolysis) on the change in the chemical composition and functional and technological properties of jellyfish is considered. The biological and energy value of raw and boiled jellyfish is calculated. Taking into account the active syneresis of jellyfish tissues (up to 60% of water is released during the first 3 hours) and the inexpediency of transporting fresh jellyfish, the preliminary heat treatment is recommended, followed by the use of the object of study in culinary products and semi-finished products, as well as enrichment as a prerequisite for obtaining original products both from the point of view of organoleptics and enhancing the nutritional value of food products. Studies with the use of freeze drying, as well as with the use of minced jellyfish to obtain a wide range of combined products are particularly noteworthy.

Keywords: scyphozoan jellyfish, *Rhizostoma pulmo*, syneresis, heat treatment, hydrolysis, yield point, nutritional value

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Научная статья

Функционально-технологические свойства и пищевая ценность медузы *Rhizostoma pulmo* (Macri, 1778)

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Аннотация. Представители желетелого планктона (в частности, сцифоидные) относятся к недоиспользуемым ресурсам Азово-Черноморского бассейна, волновой характер их размножения оказывает мощное воздействие на экосистемы двух морей. Сезонные вспышки численности ведут к увеличению пресса на кормовую базу промысловых гидробионтов, изменению структуры и качества рыбных уловов, ухудшению рекреационных условий курортных зон Азово-Черноморского бассейна. Актуальность поиска рационального решения проблемы переработки медуз *Rhizostoma pulmo* обусловлена особенностями их биохимического состава, присутствием в тканях гидробионтов биологически активных веществ, их низкой ликвидностью как сырья и сезонной ресурсной доступностью. Приводятся данные по размерно-массовому составу *Rh. pulmo*, выловленной в Азовском море, рассмотрено влияние различных видов термообработки (замораживания, варки, СВЧ-обработки, ферментативного гидролиза) на изменение химического состава и функционально-технологических свойств медуз, рассчитаны биологическая и энергетическая ценность сырца и вареной медузы. Принимая во внимание активный синерезис тканей медузы (первые 3 ч выделяется до 60 % воды) и нецелесообразность транспортировки свежей медузы, рекомендуется предварительная термическая обработка с последующим использованием объекта исследований для приготовления кулинарных изделий и полуфабрикатов, а также обогащение – обязательное условие для получения оригинальных продуктов как с точки зрения органолептики, так и в целях усиления пищевой ценности пищевых продуктов. Особого внимания заслуживают работы с применением сублимционной сушки, а также с использованием фарша из медуз с получением широкого ассортимента комбинированных продуктов.

Ключевые слова: сцифомедузы, *Rhizostoma pulmo*, синерезис, термообработка, гидролиз, предельное напряжение сдвига, пищевая ценность

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Introduction

Rhizostoma pulmo (Macri, 1778) belongs to the class of scyphoid or scyphozoa (*Scyphozoa*), marine organisms from the type of cnidaria (*Cnidaria*). A distinctive feature of the type is the presence of stinging cells (nematocysts), which serve to attack and protect the coelenterates. The upper part of the jellyfish is called "exumbrella", and the lower one is called "subumbrella". In the middle of the inner concave part of the pileus is a mouth, the corners of which pass into the oral lobes (necessary for capturing food). In root-mouthed jellyfish (order *Rhizostomeae*), they grow together and form a filtering apparatus for absorbing small plankton particles. At the edges of the pileus there are clusters of nerve cells, there are also sensory organs nearby that perceive light stimuli and help maintain balance. Scyphoids are endowed with a stomach with 4 pocket-like protrusions, and a system of radial tubules, with the help of which nutrients from the intestinal cavity are distributed throughout the body. Undigested food particles are sent back to the stomach and excreted through the mouth.

The body of jellyfish consists of two layers of epithelial cells: ectoderm and endoderm, between them lies mesoglea, i. e. a jelly-like tissue. The body of jellyfish is transparent and gelatinous, consisting of 98% water. Jellyfish, first of all, are a valuable source of protein, contain collagen, elastin, macro- and microelements, biologically active substances of various nature, i. e. hyaluronic acid, chondroitin sulfates, etc. [1, 2].

In Japan, China, Korea, Thailand, Indonesia, Malaysia and the Philippines, jellyfish have been eaten for a very long time, being called "crystal meat". Jellyfish dishes are quite exquisite dishes and delicacies. Figure 1 presents the official FAO data (2020) on the global catch of jellyfish for the period 2000-2019, however, there is an opinion that the average annual actual catch of jellyfish is underestimated and reached 900 thousand tons already in 2016 [3, 4].

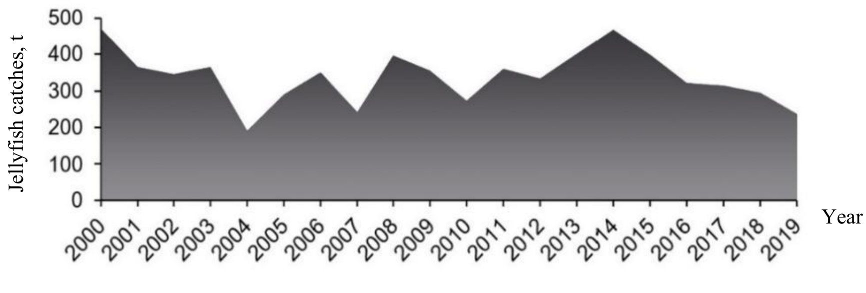


Fig. 1. World annual catch of jellyfish in 2000-2019, in tons

Representatives of the genus *Rhopilema* are of the greatest commercial importance; jellyfish gg. *Aurelia*, *Dactylometra*, *Lobonema*, *Stomolophus*, *Rhizostoma*, etc. Cornerotes (*Rhizostomeae*), *Rhopilema esculentum* (Kishinouye, 1891) and *Rhopilema hispidum* (Vanhöffen, 1888) are considered the most popular in China, Japan and Korea, *Aurelia aurita* (Linnaeus, 1758) are in demand, *Lobonema smithii* (Mayer, 1910), *Lobonemoides gracilis* (Light, 1914), *Dactylometra quinquecirrha* var. pacifica (Goette, 1886), _Nemopilema nomurai_ (Kishinouye, 1922), etc. Jellyfish are used pickled, salted, dried, dried and canned; the cooking process includes the removal of oral lobes, digestive and genital organs, and mucus. Sushi, noodles, ice cream are prepared from jellyfish, they are included in salads, soups and confectionery.

In the Azov-Black Sea basin there are 2 species of jellyfish, except for _Rh. pulmo_, _A. aurita_ – "moon jellyfish" or "Black Sea eared jellyfish". The annual recommended volume of production (catch) of jellyfish in the Sea of Azov is 966.2 tons, in the Black Sea – 987.8 tons [5]. However, at present, jellyfish are not included into the commercial yield. It should be noted that the population of jellyfish has increased significantly only in recent years; this is associated with a decrease in severe food competition on the part of ctenophore _Mnemiopsis leidyi_ (A. Agassiz, 1865) [6].

Rh. pulmo is a large and heavy jellyfish with purple edges and developed oral lobes. The contact with scyphomedusa can cause erythematous and ulcerative lesions. Rare cases of dermatitis are described as mild erythema spontaneously disappearing after a few hours, although burning of the skin and especially of the lips, sneezing, rhinorrhea, urticaria and systemic symptoms have been reported [7]. From nematocysts _Rh. pulmo_, a very large hemolytic protein (cytolysin), called rhizolysin, with a molecular weight of about 260 kDa was isolated [8]. It was found that the tissues of _Rh. pulmo_ taken from the oral cavity and devoid of nematocysts have a strong cytotoxic activity against cultured cells and show IC_{50} values in the range from 16.9 to 49.9 µg protein/ml depending on the origin of the tissue (from the outer to the inner part of the oral lobe, respectively) [9, 10].

Scientists of the Russian Research Institution of Fisheries and Oceanography "VNIRO" (Kerch branch "AzNIRKh") [11-13] found that the content of toxic elements in raw jellyfish did not exceed the permissible limits (Table 1).

Table 1

Content of toxic elements in _Rhizostoma pulmo_*

Toxic elements	Contents, mg/kg of raw weight	Permissible limit, mg/kg, no more
Lead	< 0.05	10.0
Cadmium	0.032 ± 0.010	2.0
Mercury	< 0.005	0.2
Arsenic	< 0.50	5.0

*See data [11].

There was evaluated the preliminary shelf life of jellyfish chilled at a temperature of (4 ± 2)°C for 4 days, and jelly frozen at a temperature of (–18 ± 2)°C for 5 months. Moreover, samples of salt-dried semi-finished product were taken.

While cooking, "crystal meat" easily takes on the smells of the products with which it is cooked. Since jellyfish meat does not have its own pronounced smell, it goes well with various hot seasonings and spices: black and red peppers, soy sauce, nutmeg, etc.

The problem of finding an effective integrated technology for processing jellyfish in the Azov-Black Sea basin lies in the high water content of the tissue and, accordingly, the low content of solids and the yield of finished products. The use of potassium alum when salting jellyfish reduces the quality of dried products, alum gives a strongly pronounced astringent taste, after additional cooking and soaking, the consistency of the exumbrella of Azov jellyfish deteriorates, and the crunchy sound of the tissue is lost.

The purpose of the study is to use raw materials (_Rhizostoma pulmo_) rationally, purposefully regulate the quality characteristics of the semi-finished product and finished products, taking into account the functional and technological properties and nutritional value of jellyfish.

Materials and methods

The object of research was the Azov jellyfish _Rh. pulmo_ caught in July-September 2020-2021 (45º 34' 98. 94" N, 36º 47' 52. 53" E, 45º 17' 43. 6" N, 36º 25' 56. 5" E). Samples were taken according to standard methods.

A Ulab 3-31M penetrometer was used to determine the limiting shear stress. The principle of operation of the penetrometer is based on measuring the depth of immersion of a cone into a sample of the tested product at a certain test temperature and load for a certain time. The measured value is expressed in penetration units corresponding to tenths of a millimeter (0.1 mm).

The ultimate shear stress (θ) was calculated using the formula by P. A. Rebinder:

$$\theta = km/h^2,$$

where θ is ultimate shear stress (USS), Pa; _k_ is constant, which for a cone with an angle at the apex 2 α = 60° equals 2.1 N/kg; _m_ is weight of the cone with rod and additional weight; _h_ is immersion depth of the cone during 5 s, m.

Studies of the chemical composition were carried out using standard methods adopted in a comprehensive chemical analysis, namely: a total content of nitrogenous substances – according to the Kjeldahl method using a FOSS auto-nitrogen analyzer; mineral substances – gravimetrically, after burning at a temperature of 600-700 °C, the composition of macro-and microelements – by capillary electrophoresis.

The protein-water coefficient of jellyfish (%) was calculated as the quantitative ratio of protein to water. Lipid-protein ratio (%) was assessed as the ratio of lipid to protein in the muscle tissue. The coefficient is an indicator of the tenderness of the consistency of meat of aquatic organisms. The food saturation coefficient was determined by the ratio of the sum of proteins, fats and carbohydrates to the mass fraction of water in raw materials [14].

Jellyfish nutritional value was assessed in accordance with the requirements of the technical regulation of the Customs Union TR CU 022/2011 [15].

Assessment of the biological value of jellyfish proteins was carried out according to the method of H. H. Mitchell & R. J. Block [16], in accordance with which the index of amino acid scores is calculated.

Results and discussion

The size-weight composition was determined on 121 specimens of freshly caught jellyfish (Table 2).

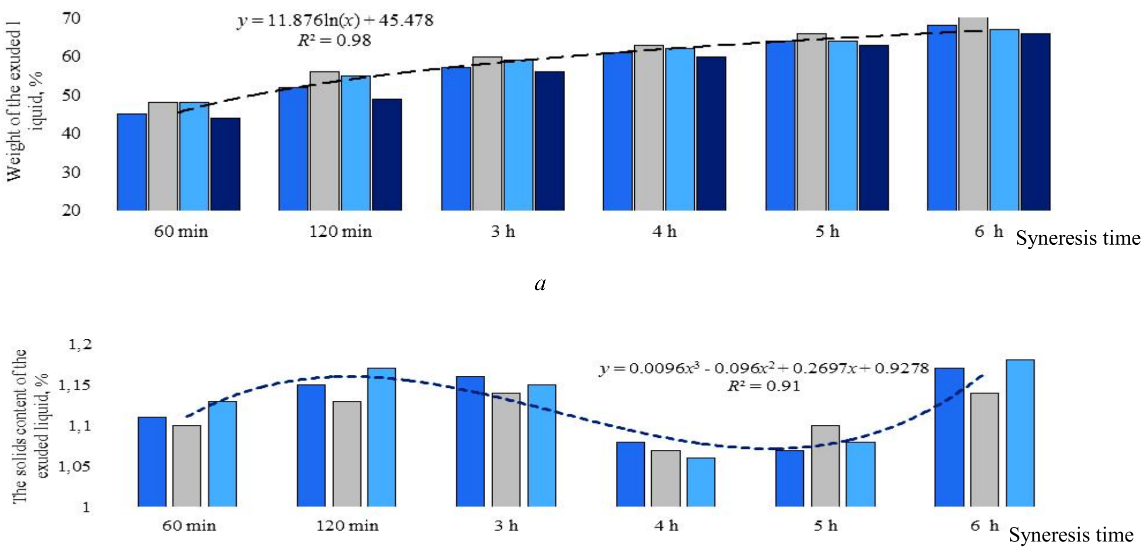
Table 2

Weight composition of *Rhizostoma pulmo*

Month of catch	Number of samples, *n*	Weight of the whole jellyfish, g	Umbrella		Oral lobes
			Weight, g	% weight of the whole jellyfish	% weight of the whole jellyfish
2020					
July	24	2 496.0 ± 172.2	1 225.1 ± 87.1	49.1 ± 0.68	50.9 ± 0.80
August	20	4 534.3 ± 191.6	2 052.1 ± 78.2	45.4 ± 0.65	54.6 ± 0.65
September	32	2 555.4 ± 164.8	1 350.6 ± 81.3	52.5 ± 0.67	47.5 ± 0.72
2021					
August	25	3 845.2 ± 120.0	2 345.5 ± 65.2	61.0 ± 0.45	39.0 ± 0.50
September	20	2 430.5 ± 115.0	1 414.6 ± 70.8	58.2 ± 0.58	41.8 ± 0.64

The size of the pileus varied from 16 to 40 cm, averaging (32.6 ± 1.6) cm. The thickness of the pileus in the center was (4.0 ± 1.0) cm, and 1-2 cm along the edges. As noted earlier [12], the largest size of jellyfish was recorded in August.

Jellyfish is a living jelly, which, when frozen, followed by defrosting or drying, is destroyed as an irreversible colloidal system. The water in the tissues of the jellyfish is not firmly bound, therefore, after the catch; a spontaneous separation of the liquid occurs (the phenomenon of syneresis). The jellyfish flows continuously, but most of the liquid phase is released during the first 3 hours (up to 60%), while the integrity of the umbrella does not matter. The research results are presented in the histogram (Fig. 2).



b

Fig. 2. Syneresis of a freshly caught jellyfish: *a* – weight of released liquid (4 samples); *b* – dry matter in the released liquid

A high content of mineral substances (up to 80.0% a.d.w.) was determined in the composition of the released liquid, chlorides account for at least 95%, protein substances (No. 6.25) make up 5.5-5.6% a.d.v.

Taking into account the active syneresis of jellyfish tissues, as well as the appearance of a sharp unpleasant odor during 10-12 hours of storage at ambient temperature, which in the summer season reaches 30 °C and above, the duration of storage/transportation of freshly caught jellyfish should not exceed 3-4 h. For the purpose of dehydration, jellyfish are subjected to heat treatment or salting, the oral lobes, gastrovascular system are previously removed, washed and, taking into account the duration of transportation, are exposed for natural removal of water. Salting to a salinity of the product from 4.0 to 7.0% is carried out in a complex fixing medium (dry salting: table salt and alum in a ratio of 10 : 3) in two stages with a change in the resulting brine (I - 2 days, II - 1 month), which ensures long-term storage of food jellyfish. The appearance is unattractive for the consumer – a thin translucent film (thickness 1-2 mm) with a salt content of up to 20% (Table 3).

Table 3

Chemical composition of *Rhizostoma pulmo*

Object of research	Weight fraction, % a.d.v.			
	Protein (No. 6.25)	Fat	Ash	Carbohydrates
Fresh jellyfish	28.4	0.6	60.6	10.4
Salted jellyfish	20.5	1.1	68.9	9.5

The yield makes 1.5%. It is also not possible to use salted jellyfish as a semi-finished product: when soaked, the tissues do not swell, and there is no airiness or a crispy texture.

When boiled without water, the tissues of the jellyfish acquire a grayish tint and thicken; foam flakes (extractive substances) appear, and the specific smell disappears. When cooked for 20 minutes, the yield was 7.6-7.8%, the longer the cooking time, the lower the yield of boiled jellyfish. The mass fraction of proteins was 16.3%, fat – 1.8%, ash – 4.07% (water 74.0%). When cooking fresh pilei of jellyfish in water (GM 1 : 2-1: 4, 20-25 min), the yield of chilled boiled semi-finished jellyfish is 15.0-17.0% of the mass of raw materials, when cooking frozen pilei – 0.7% of the mass of raw materials.

After defrosting and removing water, the jellyfish pileus was subjected to microwave treatment, which made it possible to heat the tissue throughout the entire volume at once, the average heating rate being 0.3-0.5°C per second. The ultimate shear stress (N/m^2) in the jellyfish tissue after defrosting and its change after 1, 2, and 3 min of treatment were assessed (Fig. 3).

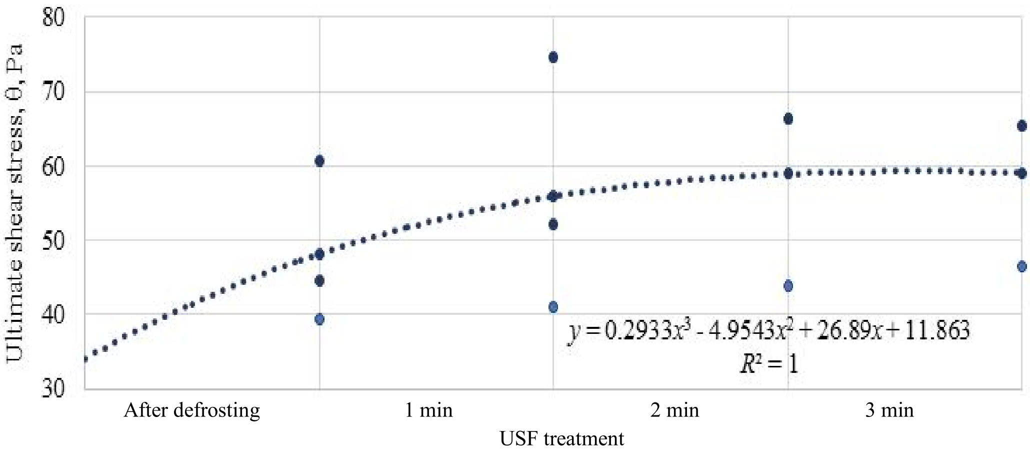
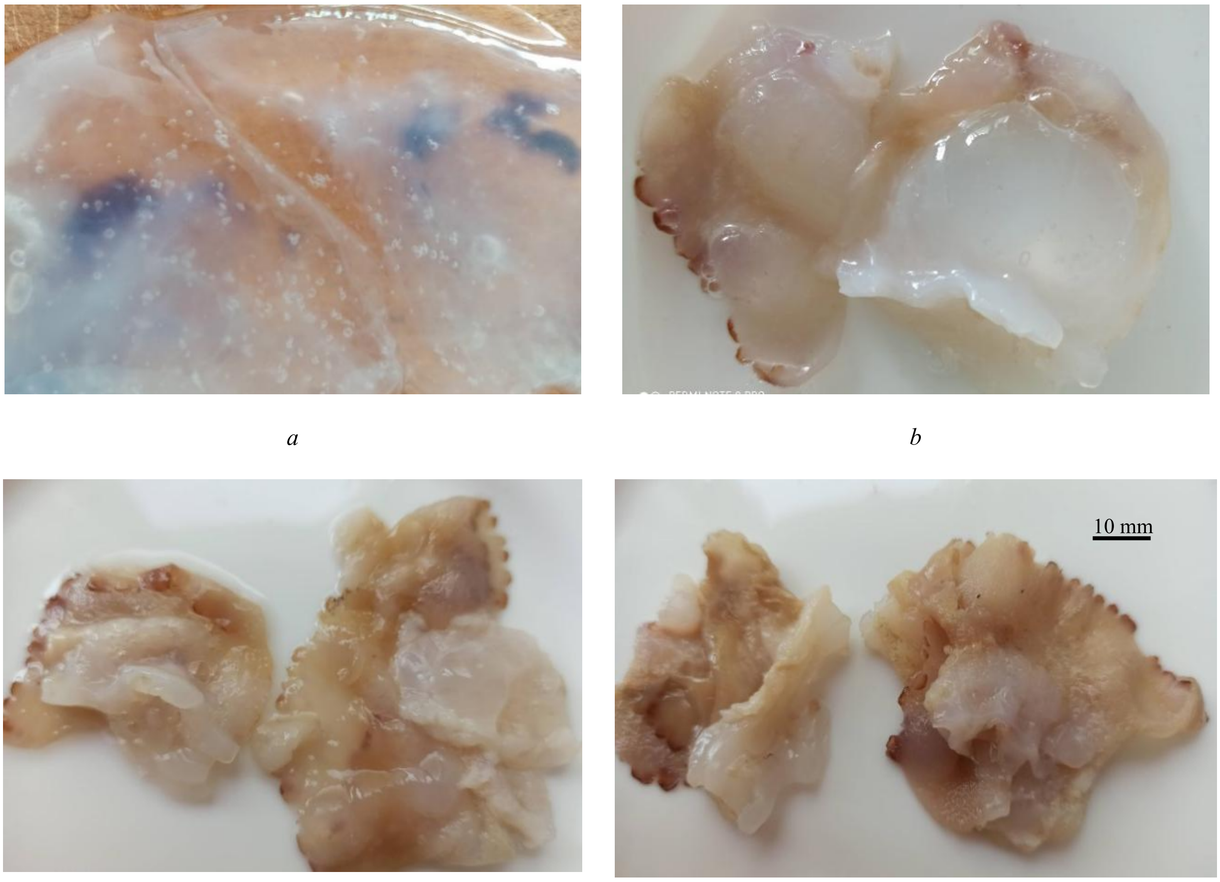


Fig. 3. Variation of the ultimate sheer stress in the jellyfish tissue

Active separation of tissue fluid (100-150 ml) occurs in the first two minutes of microwave treatment (from smaller pilei for the 1st minute, large ones – for the 2nd), the weight of the pileus decreases by 4 times, respectively, the removal of the liquid affects the change in rheological parameters (tissue turgor), as a result of 2 minutes of processing, the value of the limiting shear stress increases by 10 Pa.

The appearance became more attractive than that of a boiled jellyfish; the transparency of the tissues was preserved only after 1 minute of treatment; turgor and a subtle marine smell disappeared after 2 minutes of treatment. Processing of 3 minutes is impractical, because moisture separation does not occur; the appearance has not changed (Fig. 4).



a *b* *c* *d*

Fig. 4. Appearance of samples before and after microwave treatment of jellyfish tissues:
a – after defrosting; *b* – microwave treatment for 1 min; *c* – 2 min; *d* – 3 min

The water content in the samples is 73.7-74.4%, the yield is 18.8-19.0% of the original sample (after defrosting), 1.5-2.3% raw jellyfish.

Minced jellyfish were treated with alcohol (96°) at a ratio of 1 : 1.5; as a result of extraction, the minced meat acquired a milky hue, fibrous-cotton consistency, the smell of the sea is more pronounced than that of boiled and microwave-treated jellyfish; moisture content – (86.9 ± 0.8)%, yield – 9.1%. The sediment was dried (yield 1.5%), alcohol (55°) was sent for regeneration.

Minced meat was also subject to hydrolysis with a proteolytic enzyme (Novozymes Alcalase 2.5L) for 15 min, hydromodulus 1 : 1. The hydrolyzate is a jelly-like liquid with an even grayish color, did not separate during storage, and upon concentration (vacuum evaporation) acquired a pinkish-cream shade by a factor of 20. Probably, the structural proteins of the jellyfish form complexes with glycosaminoglycans. Hydrolysis was also carried out with another proteolytic enzyme, pepsin, which has collagenase activity. Hydrolyzed collagen is a highly demanded product in cosmetology and pharmacology. It is known that jellyfish collagen had a suppressive effect on antigen-induced arthritis in experimental animals [17].

Using freeze-drying of tissues of the Far Eastern jellyfish *Rhopilema asamushi* (up to 8-10% dry matter) showed an increase in the content of the mineral component in comparison with raw material by 2.1 times, carbohydrates by 3 times, a decrease in the weight fraction of proteins by 2.3 times (0.21 mg/g – raw protein, 0.09 mg/g – in freeze-dried) [18]. The content of collagen in freeze-dried jellyfish was found to be 78.7 mg/g [18], jellyfish collagen is poorly soluble and contains one protein fraction of 220 kDa [19].

The results of the analysis of the amino acid composition of the protein of raw jellyfish and boiled *Rh. pulmo* are presented in Table. 4.

Table 4

Indicators of the biological value of protein of *Rhizostoma pulmo*

Name of the indispensable amino acid	Content, g/100 g of product	Content, g/100 g of protein	Content, g/100 g of the ideal protein (by FAO/WHO)	Amino acid score, %
Raw jellyfish (protein – 0.34%, 28.57% absolute dry matter)				
Valine	1.25	4.36	5.00	87.2
Isoleucine	1.21	4.21	4.00	105.3
Leucine	1.71	5.93	7.00	84.7
Lysine	2.90	10.07	5.50	183.1
Methionine	0.09	0.66	3.50	18.9
Threonine	1.62	5.63	4.00	140.8
Tryptophane	0.28	0.97	1.00	97.0
Phenylalanine + Tyrosine	0.71 + 0.59	2.48 + 2.06	6.00	75.7
Boiled jellyfish (protein – 1.67%, 62.55% absolute dry matter				
Valine	3.03	4.93	5.00	98.6
Isoleucine	3.04	4.85	4.00	121.3
Leucine	4.67	7.46	7.00	106.6
Lysine	7.97	12.71	5.50	231.1
Methionine	0.76	1.21	3.50	34.6
Threonine	3.98	6.34	4.00	158.5
Tryptophane	0.82	1.32	1.00	132.0
Phenylalanine + Tyrosine	1.99 + 1.83	3.17 + 9.71	6.00	214.7
	Raw jellyfish		Boiled jellyfish	
Amino acid score dissimilarity coefficient, %	71.2		86.9	
Biological value, %	28.8		13.1	
Amino acid composition utility factor, *U, U→1*	0.19		0.14	

As it can be seen from the data below, all essential amino acids are present in the protein of the jellyfish, however, the limiting amino acids in raw are methionine, leucine, valine, phenylalanine (biological value (BC) – 28.8%), in boiled jellyfish – methionine (BC – 13%), and a high content of lysine, threonine reduces the protein balance coefficient (0.19 and 0.14, respectively). Cysteine, which is a precursor of methionine, was not found in the experiment. The protein also contains conditionally essential amino acids – arginine (raw 7.03% protein, boiled jellyfish – 7.70%) and histidine (1.57 and 2.29%, respectively). A high content of non-essential amino acids was noted: glycine (12.78 % in raw, 3.84% in boiled jellyfish), aspartic (9.09 and 10.07%), glutamic (16.20 and 15.78%) acids [20].

Table 5 shows the diverse composition of microelements in *Rh. pulmo*, their content is significantly lower than the daily physiological requirement of an adult.

Table 5

Mineral composition of raw jellyfish tissues *Rhizostoma pulmo*

Element	Content, % total mineral content	Element	Content, % total mineral content
Copper, Cu	0.0004-0.0006	Vanadium, V	< 0.001
Manganese, Mn	< 0.001	Titanium, Ti	0.0011-0.0012
Iron, Fe	0.01-0.015	Nickel, Ni	–
Aluminium, Al	0.015	Barium, Ba	0.001
Zinc, Zn	< 0.1	Strontium, Sr	0.0372-0.0447

Energy value of 100 g of raw jellyfish is 13.3 kJ, boiled – 398.8 kJ, salted – 172.9 kJ, in any case, jellyfish belongs to low-calorie foods and can be proposed for the diets of overweight people.

Conclusion

When solving the problem of rational use of the *Rhizostoma pulmo* jellyfish caught in the Sea of Azov, the following factors were studied, namely: the size and weight composition of raw jellyfish, their availability, changes in the chemical composition and functional and technological properties under various processing conditions, the possibility of complex processing, enrichment and storage. The synergy of well-known developments in the sphare of research and modern methods of processing raw jellyfish with maximum preservation of inherent properties allow to infer that preliminary heat treatment is required, followed by conservation of the research object for the preparation of culinary products and semi-finished products, the prospects for enzymatic hydrolysis in the case of further obtaining a fraction of structural proteins, as well as enrichment as a prerequisite for obtaining original products, both in terms of organoleptics and enhancing the nutritional value of food products. In our opinion, treatment with freeze drying and the use of minced jellyfish with a wide range of combined products with high added value deserves particular attention.

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