DEVELOPMENT OF BIODEGRADABLE POLYSACCHARIDE-PROTEIN EDIBLE GEL COAT WITH ANTIMICROBIAL PROPERTIES FOR FOOD PRODUCTS

Elena E. Kuprina*, Anastasiya N. Yakkola, Andrey N. Manuylov, Elena I. Kiprushkina, Irina A. Shestopalova, Pavel I. Demidov**

ITMO University, Faculty of Biotechnologies
Lomonosov street 9, RU191002 Saint-Petersburg, Russia

**e-mail:* elkuprina@yandex.ru

***e-mail:* shokoladnitsa@list.ru

Abstract

Food edible coatings are an important milestone in food production and one of the innovations in food packaging development. This article presents materials on the development of the formulation and technology for the manufacture of a novel composite coating based on sodium alginate, chitosan and protein hydrolysate obtained by the electrochemical method of double extraction from cod processing waste to obtain edible coatings for semi-finished fish products. Furthermore, the physicochemical, physical, mechanical and microbiological properties of this material are described.

Keywords: *chitosan, sodium alginate, protein hydrolysate, biodegradable food films and coatings, formulation, technology, mechanism of formation, ediblefilms and coatings, environmental protection, sensory, physicochemical, physical and mechanical, antimicrobial properties.*

Received: 03.03.2021
Accepted: 15.06.2021

1. Introduction

Food packaging is the final step in the manufacturing process of food, ensuring its safety as well as protecting it against damage and deterioration [1, 2]. Regular packaging is thrown away by the consumer immediately after using the packaged contents and finds its way into landfills or oceans [3]. Most of the materials used for packaging are non-biodegradable and when incinerated, toxic substances and carbon dioxide (CO_2) are emitted, which imposes a huge burden on the environment [4].

Currently, there is growing interest in the development and application of edible coatings due to their versatility and the possibility of using various active substances as carriers, such as antioxidants and antimicrobial agents [5, 6]. Edible coatings are an integral part of the food [7], so the choice of ingredients and the method of processing depend on the food to be packaged. In addition, the coating must have sensory compatibility with the packaged food product [8].

The main functions of edible coatings are to extend the shelf life of food, maintain food quality and reduce waste. For edible packaging, non-toxic, environmentally friendly materials should be used, with a minimum or no disposal period [9] – for example, chitosan/chitin, starches, cellulose derivatives, animal or vegetable proteins and lipids [10]. The compounds should be biocompatible, moisture and/or gas tight, suitable for extending the shelf life of the product [11] and pose no risk to human health.

One of the current approaches to creating edible packaging is the use of physically or chemically bonded hydrogels. Their advantages are the ability to maintain or even increase the water-holding capacity of the product during storage and heat treatment. Of particular interest is the study of the mechanism of the formation of gels, which makes it possible to influence purposefully their physical, mechanical and consumer properties [12].

In foods, hydrogels are used to increase the stability and bioavailability of bioactive food ingredients [13]. Physical gels are most common due to pH changes, heating/cooling, high pressure processes or the addition of ions, which are common methods for the formation and structuring of gels in foods. [14]. Physical gels also include emulsion gels. The emulsion droplets are more stable in three-dimensional space in the gel network. In addition, the characteristics of emulsion droplets affect the viscoelastic parameters of the system [15].

While fish and meat are extremely perishable foods, but they are of great value in human nutrition, as a source of complete protein. Therefore, edible coatings for meat and fish products are of particular interest. Such packaging could increase the shelf life, improve organoleptic properties and prevent moisture loss during the preparation of these products [16-18]. In addition, edible packaging is able to reduce biochemical spoilage of the product, partially protect against lipid oxidation, prevent proteins from hydrolysis and prevent unwanted discolouration.

The aim of the work was to develop an edible gel thermostable coating for fish and its processed products with satisfactory physical and mechanical characteristics, specifically to prevent the loss of moisture in the product during storage and heat treatment, to improve the sensory properties and to increase the shelf life.

2. Materials and Methods

2.1. Sampling

High-molecular chitosan from crustacean shells (ZAO Bioprogress, Russia) with a molar mass of 224,500 g/mol and a deacetylation degree of 98% was used. The mass fraction of minerals in chitosan did not exceed 0.46%, moisture did not exceed 10% and insoluble substances did not exceed 0.3%. For the preparation of chitosan solutions, 1-aqueous citric acid (ultra-pure grade GOST 3652-69) was used.

Table 1. Physicochemical properties of protein hydrolysate from cod skin and bones obtained by electrochemical double extraction

Raw material	**N total (%)**	**N amine (%)**	**Protein (%)**
Protein hydrolysate obtained from cod skin and bones	1.34	0.25	8.5

Sodium alginate from Japanese kelp seaweed with a molar mass of 63000 g/mol was used. It is 100% soluble in water, has an ash content of 17.6%, 13.5% humidity and 0.3% insoluble substances.

Calcium chloride (analytical grade, white granules) was used.

Collagen hydrolysate was obtained from cod-skin and bone waste by the electrochemical method of double extraction [19, 20]. The physicochemical characteristics of the protein hydrolysate are presented in Table 1.

Distilled water was obtained by distillation using a DE-10 distiller and had the following quality indicators: pH = 6.0; electrical conductivity = 5×10^{-5} S m^{-1}

Chilled minced cod fillet was chosen used for the study, on which the coating was applied. This fish is important commercially and has high nutritional qualities and energy value, characterised by a high protein content. In addition, it has a short shelf life, up to 72 h at temperatures from 0 to 5°C [21].

2.2. Research Methods

2.2.1. Analytical Methods

Amine nitrogen was determined by formol titration [22].

The deacetylation degree was determined by potentiometric titration as described in [23].

The molecular weight of chitosan was determined in a solution containing 0.3 M sodium chloride and 0.33 M acetic acid in 1 l, and sodium alginate in 0.1 M sodium chloride [24].

The content of functional groups in polymers was determined according to previously reported methods [24, 25], namely by using the potentiometric method on an ANION 4100 ionometer with a glass combined electrode (Δ = 0.05 pH, t = 230°C). The content of free carboxyl groups (Kc, %) in sodium alginate was calculated by using Eq. (1):

$$Kc = \frac{C_{NaOH} \cdot V_{NaOH} \cdot 45}{m_{alg} \cdot 1000} \cdot \frac{V_{flask}}{V_{alg}} \cdot 100\%, \quad (1)$$

where $m_{alg.}$ is the weight of the polysaccharide (g), 45 is the coefficient of equivalence of alkali to carboxyl groups and V_{NaOH} is the volume of alkali used for titration, ml.

2.2.2. Sensory Research Methodology

The samples were placed on a white enamel tray, arranged so that they were not in contact with each other. To determine the consistency in the middle, most fleshy part of the sample, a transverse incision was made and the index finger was pressed onto the surface at the incision site. The smell of fish was determined by using a heated knife, which caused the release of volatile ammonium and other nitrogen-containing compounds from the minced meat. The samples were investigated in a similar way on day 9 of cold storage.

2.3. Physical and Mechanical Test Methodology

2.3.1. Determination of Strength Characteristics

The strength characteristics of film coatings were determined by using a machine for testing structural materials UTS-101-5-1-U (Figure 1).

The thickness of the polysaccharide-protein gel coat was measured with a digital micrometer. To measure the thickness of the gel coating, one measurement was made in the centre of the sample and four measurements were made at different regions of the coating perimeter. Then, the average value of the film thickness was calculated.

Studies of strength characteristics and thickness were carried out in accordance with GOST 14236-81.

The tensile test of the film materials was carried out at a load application rate of 100 mm/min. Samples with a width of 10 mm were tested with a clamping distance of 50 mm.

The percentage elongation at break was calculated by using equation (2):

$$\delta = \frac{L}{h} * 100\%, \quad (2)$$

where L is the elongation at break (mm) and h is the distance between the clamps of the tensile testing machine (mm). Materials with $\delta > 10\%$ are plastic, and materials with relative elongation $\delta < 3\%$ are brittle.

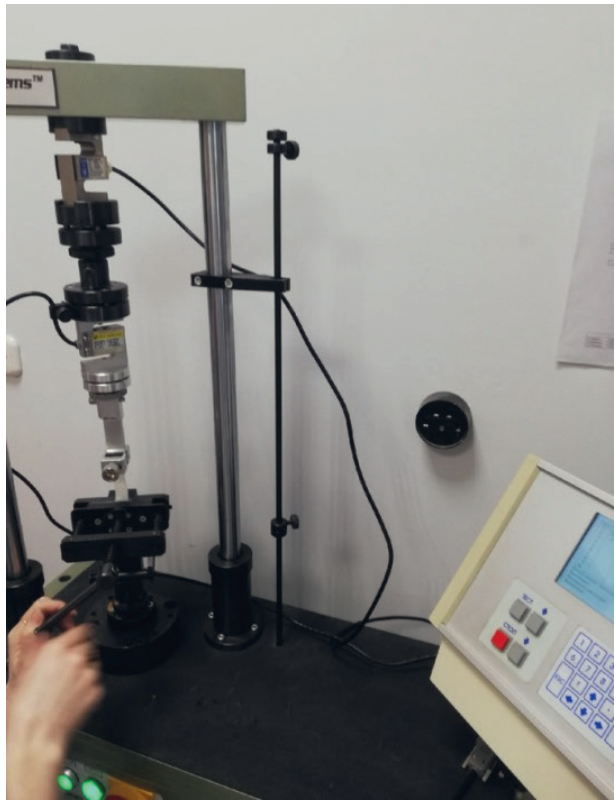

Figure 1. Determination of strength characteristics on a machine for testing structural materials (UTS-101-5-1-U)

2.3.2. Determination of Elasticity

The elasticity of the studied fish samples with film coatings was evaluated with the Valenta VZ1 device. This apparatus uses the principle of measuring the force acting on a glass with a sample when a mushroom nozzle is immersed in it. To do this, a glass with a sample is placed on a digital scale, a mushroom-shaped nozzle is placed on top of the surface, which is connected through the AC motor shaft. The rotation of the motor shaft is converted into a uniform movement of the mushroom nozzle, which is smoothly immersed in the sample, while the balance shows the force of the pressure of the nozzle. At the moment of the breakthrough, the maximum weight is recorded on the scales. After the nozzle enters the sample, the balance readings begin to decrease, as the resistance falls. At the same time, the pressure of the nozzle on the jelly can be recorded through a communication device on the screen of a computer.

2.4. Physicochemical Research Methodology

After applying the film-forming composition, the weight of the test samples was recorded using a balance and the samples were placed in a refrigerator at 5 ± 0.1°C. The weights were compared before and after the application of gel coatings, and the shrinkage values of the samples were calculated. Similarly to the above-described method, the weight loss of the samples was investigated during heat treatment (during cooking).

2.5. Microbiological Research Methodology

2.5.1. Quantity of Mesophilic Aerobic and Facultative Anaerobic Microorganisms (QMAFAnM)

The method to determine QMAFAnM is based on the possibility of mesophilic aerobic and facultative anaerobic microorganisms to multiply on a solid nutrient medium at 30 ± 1°C for 72 h. When determining QMAFAnM, dilutions from 10^{-1} to 10^{-4} were inoculated into the nutrient medium from each sample. In Petri dishes with a pre-marked lid, 1 cm^3 of each dilution was inoculated and 10-15 cm^3 were added to melted mesopatamia agar (MPA) cooled to 40-45°C. Immediately after pouring the agar, the contents of the Petri dishes were thoroughly mixed by gentle rotation for even distribution of the inoculum. After the agar had solidified, the Petri dishes were turned upside down and incubated at 30°C for 72 h. After cultivation, the number of colonies grown on MPA plates was counted. A magnifying glass (8× magnification) was used for counting. The number of mesophilic aerobic and facultatively anaerobic microorganisms in 1 cm^3 of the sample was calculated according to equation (3):

$$X = n \times [\![10]\!]\hat{} \, m, \tag{3}$$

where n is the number of colonies counted on a Petri dish and m is the number of tenfold dilutions.

2.5.2. Quantity of Coliform Bacteria

Five millilitres of each sample were added to tubes with 10 ml of Heifetz's medium. The inoculations were incubated at 43°C for 18-20 h. The medium did not change to a yellowish colour. For the final conclusion about the absence of *Escherichia coli* in the samples of bacteria, the inoculation was carried out on Levin's medium. These inoculations were incubated at 37°C for 18-20 h. There was no characteristic change in the environment.

3. Results and Discussion

To solve the problem of developing a new gel coating that combines two thermodynamically incompatible polysaccharides in one composite material, we proposed using the emulsion type of gelation [10]. To create an edible coating, substances allowed for use in the food industry were selected: citric acid was chosen as the solvent for chitosan due to its advantages over acetic acid, and vegetable oil provides low permeability to water vapour and a relatively good barrier properties to moisture. In addition, it would eliminate the need to use oil when frying a semi-finished product. Chitosan and sodium alginate form viscous solutions that could form a gel structure during physical or chemical crosslinking. However, when the hardener calcium chloride is added, the gel only forms with the alginate, while chitosan is released as an independent phase, a factor that could reduce the integrity of the gel. Therefore, we proposed to combine these two polysaccharides as part of oil-protein emulsion.

Chitosan and the alginate solution were mixed by introducing it into a protein-oil emulsion, which prevents chitosan from being excluded into an independent phase. The key factor in obtaining a chitosan emulsion (ChE) is the interaction of chitosan with citric acid due to the formation of an ionic bond between negatively charged carboxyl groups and positively charged protonated amine groups of chitosan. At the same time, the surface charge of substances decreases and the distance between particles decreases due to electrostatic adsorption and the elimination of bound water molecules on the surface of the polymers, thereby inducing the non-polar nature of the resulting complex.

Because the complex is non-polar, it is able to penetrate the inner part of the emulsion cell. To form an emulsion, vegetable oil was mixed with a surfactant, namely proteins [26, 27]. Specifically, the surfactant was a protein hydrolysate obtained by the method of double extraction during the electrochemical processing of cod skin and bones, which are considered waste (not consumed) [20].

On the surface of the droplets, a layer of emulsifier molecules is formed; it increases elasticity and viscosity, and thus prevents droplets from merging (Figure 2). This factor plays an important role if a high molecular weight protein or non-ionic surfactant acts as an emulsifier.

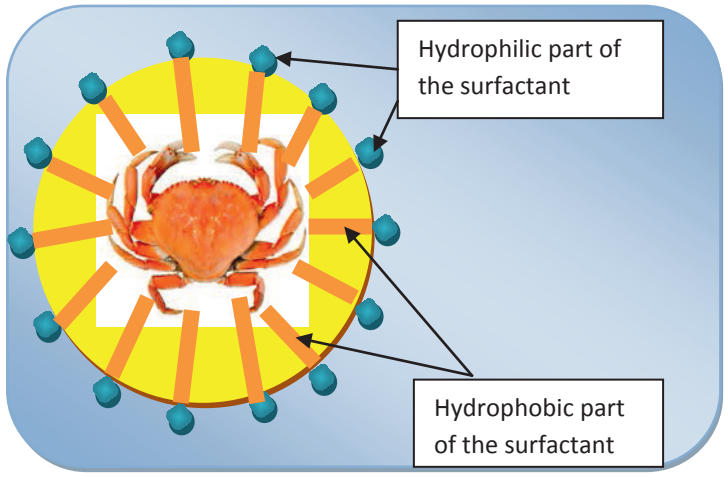

Figure 2. Conditional image of micelle emulsion oil in water with the inclusion of chitosan and protein

Due to this interaction, the storage-stable mixture of two polysaccharide solutions, sodium alginate and chitosan, was obtained. The prepared mixture was applied to the prepared surface and poured with a solution of calcium chloride. This approach allowed the formation of a gel coating proceeded.

To prepare samples of biodegradable film, we used a solution of chitosan in citric acid, a protein hydrolysate obtained from cod cuttings, an aqueous solution of sodium alginate and liquid vegetable oil. To obtain a protein-polysaccharide emulsion, a 2%-3% solution of chitosan in 3%-5% citric acid, a 1%-3% aqueous solution of sodium alginate, a protein hydrolysate (Table 1) and refined sunflower oil were used. The components were mixed for 2 min at 14,000 rpm under normal conditions. Films were prepared by pouring the solution into Petri dishes, then curing was carried out with 2%-5% calcium chloride solution for 15 min under normal conditions (Figure 3).

The food-grade biodegradable gel coating produced by this method had a thickness of 0.2-1.5 mm, which was adjusted by introducing different amounts of the mixture. In this work, the influence of the ratio of the components in the formulation on the physicomechanical, microbiological and other properties of the coating was examined. Table 2 shows the optimal intervals for the components included in the composition of the obtained polysaccharide-protein gel coating.

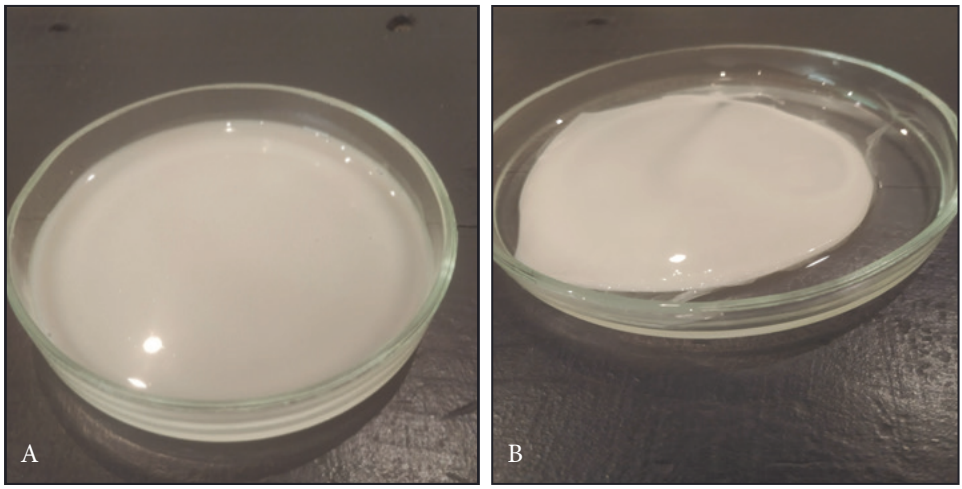

Figure 3. Photographs of the protein-polysaccharide film-forming mixture: (A) before hardening and (B) after hardening

Table 2. Composition of the polysaccharide-protein gel coating

Material	**Quantity (%)**
2%-3% solution of chitosan in citric acid	6.0-10.2
Vegetable oil	10.0-15.0
Protein hydrolysate	13.2-18.4
1%-3% sodium alginate solution	53.0-76.4
Calcium chloride solution	not limited

Each component is indicated as an interval because depending on the properties required for the coating – for example, high elasticity or high strength – the number of components can vary, but they should not go beyond the indicated ranges. In the mixture, vegetable oil was used to form micelles, inside which a chitosan-citrate complex was introduced, which provides antimicrobial properties to the product. The protein hydrolysate from cod cuttings was used as emulsifier to prevent coalescence of oil droplets and to make the coating more elastic. Sodium alginate provided the mechanical strength of the coating and protected the food product from oxygen penetration.

The sensory properties of the coating corresponded to the characteristics of the packaging materials. The surface of the film was homogeneous, without cracks, brittle zones and bubbles; the consistency was dense, without the inclusion of undissolved and foreign particles. It had a pronounced matte white colour, was tasteless and odourless and had good chewability.

The moulded minced cod products were moistened with the prepared film-forming composition, which was instantly fixed on the surface of the semi-finished product when the hardener (calcium chloride solution) was introduced at room temperature. The visual characteristics of spherical minced fish samples prepared from cod fillets with an applied film-forming composition, and then by immersion in a hardener, were examined (Figure 4).

The sensory, physicochemical and microbiological examinations of the samples were determined before and after their storage for 9 days in a refrigerated chamber at 0-6°C and a relative humidity of 92%-98%. Tables 3 and 4 show the results of the organoleptic study before and after storage in the refrigerating chamber of minced meat samples prepared from cod fillets in a polysaccharide-protein gel coating.

Samples with obvious signs of spoilage were not tasted. Changes in sensory quality indicators during storage of fish products in the refrigerated chamber at 0-6°C and relative humidity of 92%-98% are shown in Figure 5.

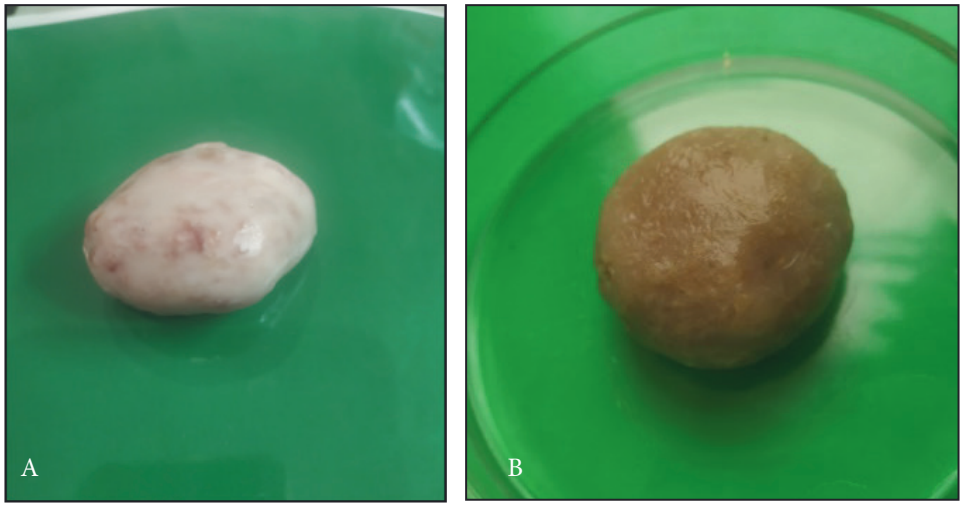

Figure 4. Photographs of the experimental appearance of the samples (A) before storage and (B) after 9 days of storage at 0-6°C

Table 3. Sensory characteristics of the chilled minced fish prepared from cod fillets with polymer gel coatings before refrigerated storage

Indicators	**Minced fish with gel coating (sample 1)**	**Minced fish with gel coating (sample 2)**	**Minced fish with gel coating (sample 3)**	**Minced fish without gel coating (control sample)**
Taste	Inherent for this product	Inherent for this product	Inherent for this product	Inherent for this product
Colour	Matte white	Matte white	Matte white	Typical of minced cod fillets
Smell	Typical for this type of fish, without foreign odours	Typical for this type of fish, without foreign odours	Typical for this type of fish, without foreign odours	Typical for this type of fish, without foreign odours
Consistency	Dense, formable, homogeneous	Dense, formable, homogeneous	Dense, formable, homogeneous	Loose, homogeneous

Table 4. Sensory characteristics of the chilled minced fish prepared from cod fillets with polymer gel coatings on day 9 of storage in the refrigerator at 0-6°C and relative humidity of 92%-98%

Indicators	**Minced fish with gel coating (sample 1)**	**Minced fish with gel coating (sample 2)**	**Minced fish with gel coating (sample 3)**	**Minced fish without gel coating (control sample)**
Taste	Inherent for this product	Inherent for this product	Inherent for this product	Not determined
Colour	No colour	No colour	No colour	Dry fibrous
Smell	Typical for this type of fish, without foreign odours	Typical for this type of fish, without foreign odours	Typical for this type of fish, without foreign odours	Strong, musty smell
Consistency	Dense, formable, homogeneous	Dense, formable, homogeneous	Dense, formable, homogeneous	Loose, gelatinous, watery

https://doi.org/10.15259/PCACD.26.013

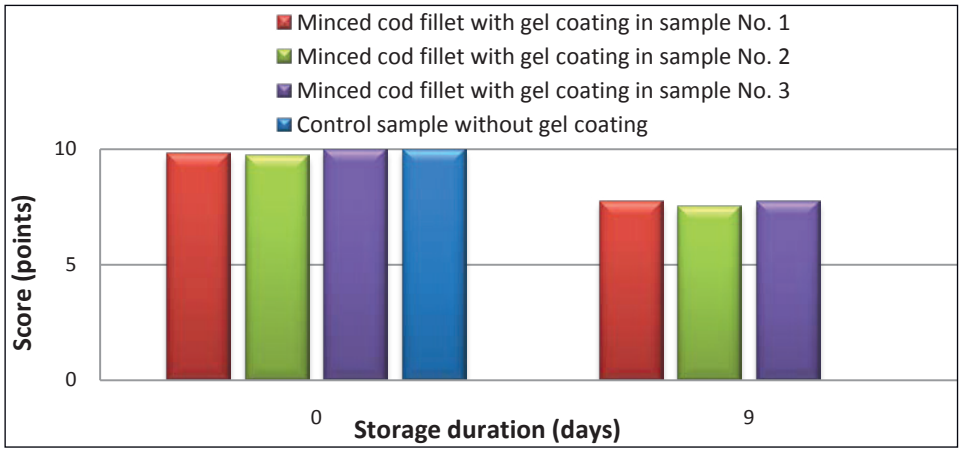

Figure 5. Histogram of changes in the sensory characteristics of test samples of minced cod fillet with the coating in comparison with the control sample during storage

Overall, application of the polysaccharide-protein gel coating maintained satisfactory organoleptic properties of the cod samples.

3.1 Physical and Mechanical Tests

3.1.1 Determination of Strength Characteristics

Because the strength characteristics depend directly on the thickness of the gel coating, the ratio of the coating thickness and the amount of composite material was investigated (Table 5).

Thicknesses were measured at five different coating points to calculate the average thickness. Based on data from the literature [28, 29], samples of gel coatings with an average thickness of about 400-600 μm were explored further.

Studies of strength characteristics and thickness were carried out in accordance with GOST 14236-81.The tensile test of the gel coatings was carried out on 10-mm wide specimens with a clamping distance of 50 mm. The results of physical and mechanical tests are presented in Table 6.

The elongation at break was calculated by using Eq. (2), substituting the data obtained during the physical and mechanical study:

$$\delta = \frac{5{,}80}{50} * 100\% = 11.60\%. \quad (2)$$

The relative elongation indicates that this gel coating is plastic and, therefore, could be used both in the manufacture of packaging materials for the food industry and applied directly to the product.

Table 5. The ratio of the thickness of the gel coating to the amount of composite material

Sample no.	Composite material (ml)	Finished gel coating thickness (μm)
1	15	400.70 ± 0.2
2	10	280.70 ± 0.2
3	5	100.42 ± 0.20

Table 6. Physical and mechanical properties of the polysaccharide-protein gel coating

Sample no.	Strength (N/mm^2)	Fm (N)	Lm (mm)	Fp (H)	Lp (mm)
1	0.201	0.81	5.06	0.78	5.22
2	0.232	0.84	5.40	0.86	5.65
3	0.254	0.93	4.04	0.56	6.05
4	0.261	1.02	8.71	0.70	9.61
Total	**0.237**	**0.90**	**5.80**	**0.73**	**6.63**

Abbreviations: Fm, maximum load at break; Lm, elongation at break; Fp, tensile load; Lp, tensile elongation

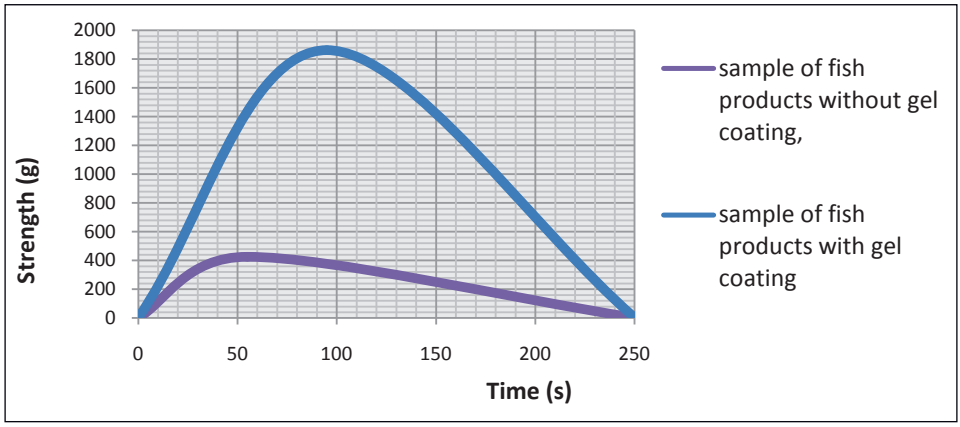

Figure 6. Indicators of strength of the investigated samples of fish products with film coatings

3.1.2. Determination of Elasticity

The elasticity of the studied samples of fish products are shown in Figure 6.

3.2. Microbiological Research

To study the antimicrobial properties of gel coatings, three samples were prepared, and the indicators of each sample were averaged. For each sample, balls of minced meat from cod fillets with a diameter of about 4 cm^3 were mixed with distilled water at a dilution of 1:10. There were three replicates for each sample; the results represent the average of the replicates. Table 7 shows the microbiological indicators.

4. Conclusions

In this study, the formulation of an edible gel coating containing polysaccharides (chitosan and sodium alginate) as well as a protein hydrolysate, obtained by electrochemical method from collagen-containing cod waste, as well as the technology to apply it to minced food products has been developed. The mechanism of formation of an emulsion-type gel coating with active filler has been put forwards. Due to the formation of a stable emulsion

Table 7. Microbiological indicators of the studied samples of fish products with and without gel coating before and after refrigerated storage at 0-6°C and relative humidity of 92%-98%

Storage duration (days)	Indicator	Minced fish with gel coating	Minced fish without gel coating
Day 1	QMAFAnM no more than 1.0×10^5	5.6×10^2	4.5×10^3
	Coliform bacteria, not allowed in 0.001 g	Not detected	Not detected
Day 9	QMAFAnM no more than 1.0×10^5	4.2×10^4	4.7×10^5
	Coliform bacteria, not allowed in 0.001 g	Not detected	Not detected
Day 10	QMAFAnM no more than 1.0×10^5	2.3×10^5	-----
	Coliform bacteria, not allowed in 0.001 g	Not detected	-----

structure, there were satisfactory physical and mechanical properties of the coatings. When testing spherical samples of minced cod, with and without coating, there were improvements in sensory properties, elasticity modulus and microbiological parameters of samples with the developed gel coating. Hence, the developed polysaccharide-protein gel coating could be applied to the surface of perishable food products to increase their shelf life.

5. References

[1] Han J.W. et al. Food packaging: A comprehensive review and future trends // Comprehensive Reviews in Food Science and Food Safety. - 2018. - T. 17. - No. 4. - S. 860-877. **DOI:**10.1111/1541-4337.12343

[2] Chen S. et al. The role of smart packaging system in food supply chain // Journal of Food Science. - 2020. - T. 85. - No. 3. - S. 517-525. **DOI:**10.1111/1750-3841.15046

[3] Zhao X., Cornish K., Vodovotz Y. Narrowing the gap for bioplastic use in food packaging: An update // Environmental science & technology. - 2020. - T. 54. - No. 8. - S. 4712–4732. **DOI:**10.1021/acs.est.9b03755

[4] Jeevahan J., Chandrasekaran M. Nanoedible films for food packaging: A review // Journal of Materials Science. - 2019. - T. 54. - No. 19. - S. 12290–12318. **DOI:**10.1007/s10853-019-03742-y

[5] Arnon-Rips H., Poverenov E. Improving food products' quality and storability by using Layer by Layer edible coatings // Trends in Food Science & Technology. - 2018 .-- T. 75 .-- S. 81–92. **DOI:** 10.1016/j.tifs.2018.03.003

[6] Petkoska A.T. et al. Edible packaging: Sustainable solutions and novel trends in food packaging // Food Research International. - 2021 .-- T. 140 .-- S. 109981. **DOI:**10.1016/j.foodres.2020.109981

[7] Aguirre-Joya J.A. et al. Basic and applied concepts of edible packaging for foods // Food packaging and preservation. - Academic Press, 2018 .-- S. 1-61. **DOI:**0.1016/B978-0-12-811516-9.00001-4

[8] Restrepo A.E. et al. Mechanical, barrier, and color properties of banana starch edible films incorporated with nanoemulsions of lemongrass (Cymbopogoncitratus) and rosemary (Rosmarinusofficinalis) essential oils // Food Science and Technology International. - 2018. - T. 24. - No. 8. - S. 705-712. **DOI:** 10.1177/1082013218792133

[9] Jeevahan J. et al. Waste into energy conversion technologies and conversion of food wastes into the potential products: a review // International Journal of Ambient Energy. - 2018 .-- S. 1-19. **DOI:** 10.1080/01430750.2018.1537939

[10] Hassan B. et al. Recent advances on polysaccharides, lipids and protein based edible films and coatings: A review // International journal of biological macromolecules. - 2018 .-- T. 109 .-- S. 1095-1107. **DOI:** 10.1016/j.ijbiomac.2017.11.097

[11] Mellinas C. et al. Recent trends in the use of pectin from agro-waste residues as a natural-based biopolymer for food packaging applications // Materials. - 2020. - T. 13. - No. 3. - P. 673. **DOI:** 10.3390/ma13030673

[12] Li J., Jia X., Yin L. Hydrogel: Diversity of Structures and Applications in Food Science // Food Reviews International. - 2021 .-- S. 1-59. **DOI:**10.1080/87559129.2020.1858313

[13] Klein M., Poverenov E. Natural biopolymer-based hydrogels for use in food and agriculture // Journal of the Science of Food and Agriculture. - 2020. - T. 100. - No. 6. - S. 2337–2347. **DOI:** 10.1002/jsfa.10274

[14] Ali A., Ahmed S. Recent advances in edible polymer based hydrogels as a sustainable alternative to conventional polymers // Journal of agricultural and food chemistry. - 2018. - T. 66. - No. 27 .-- S. 6940–6967. **DOI:** 10.1021/acs.jafc.8b01052

[15] Chen Y. (ed.). Hydrogels based on natural polymers. - Elsevier, 2019.

[16] Pabast M. et al. Effects of chitosan coatings incorporating with free or nano-encapsulated Satureja plant essential oil on quality characteristics of lamb meat // Food Control. - 2018 .-- T. 91 .-- S. 185–192. **DOI:** 10.1016/j.foodcont.2018.03.047

[17] Umaraw P. et al. Edible films / coating with tailored properties for active packaging of meat, fish and derived products // Trends in Food Science & Technology. - 2020 .-- T. 98 .-- S. 10–24. **DOI:** 10.1016/j.tifs.2020.01.032

[18] Umaraw P., Verma A. K. Comprehensive review on application of edible film on meat and meat products: An eco-friendly approach // Critical Reviews in Food Science and Nutrition. - 2017. - T. 57. - No. 6. - S. 1270–1279. **DOI:**10.1080/10408398.2014.986563

[19] Kuprina E. et al. Technology development of obtaining essential fatty acids from hydrobiontshydrolyzates // Agronomy Research. - 2019. - T. 17. - No. 6. - S. 2317–2326. **DOI:** 10.15159/ar.19.205

[20] Chikisheva M.E. et al. Development of electro-biochemical technology for processing secondary fish raw materials and new types of products based on minced fish // E3S Web of Conferences. - EDP Sciences, 2020. - T. 161. - S. 01095. **DOI:**10.1051/e3sconf/202016101095

[21] Dementyeva N.V. Justification of storage life and evaluation of quality and safety of culinary semi-finished products from macker and terbug // Scientific works of Dalrybvtuz. - 2020. - T. 53. - No. 3.

[22] Velichko N.A., Shanina E. V. Food chemistry. - 2010.

[23] Bodek, K.H. (1994). Potentiometric method for determination of the degree of acetylation of chitosan. In "Chitin World" (Z. S. Karnicki, M. M. Breziski, P. J. Bykowsky, A. Wojtasz-Pajak, Eds.), Pp. 456-461, Wirtschaftsverlag NW-Verlag, Germany.

[24] Brovko, O.S., Palamarchuk, I.A., Val'chuk, N.A., Chukhchin, D.G., Bogolitsyn, K.G., & Boitsova, T.A. (2017). Gels of sodium alginate – chitosan interpolye electrolyte complexes. Russian Journal of Physical Chemistry A, 91 (8), 1580–1585. **DOI:**10.1134/S0036024417080064

[25] Scriabin, K.G., Mikhailov, S.N. Varlamov, V.P. (2013). Chitosan.

[26] Chi Y. et al. Physicochemical properties and surface activities of collagen hydrolysate-based surfactants with varied oleoyl group grafting degree //Industrial & Engineering Chemistry Research. – 2014. – Т. 53. – №. 20. – С. 8501–8508. **DOI**:10.1021/ie5007068

[27] Li, Y., Sun, D., Jiang, C., Ding, H., & Wang, Q. (2021). Preparation of Polypeptide Surfactants Using Chromium-Containing Waste Leather: Effect of Hydrophilic and Lipophilic Groups. Journal of Surfactants and Detergents. **DOI**: 10.1002/jsde.12513

[28] Valdés, A., Ramos, M., Beltrán, A., Jiménez, A., & Garrigós, M. C. (2017). State of the art of antimicrobial edible coatings for food packaging applications. Coatings, 7(4), 56. **DOI**: 10.3390/coatings7040056

[29] Sahraee, S., Milani, J.M., Regenstein, J.M., & Kafil, H.S. (2019). Protection of foods against oxidative deterioration using edible films and coatings: A review. Food Bioscience, 32, 100451. **DOI**: 10.1016/j.fbio.2019.100451