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Minced products from undersized sea fish: new industrial technology

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Abstract:
Introduction. The ever-growing world population and protein deficiency increase the demand for products of animal origin, especially fish-based. However, canned foods and fillets, which are the most popular types of fish products, are made from medium-sized and large fish. In spite of the fact that undersized fish is cheap, it requires manual processing and remains so time and labour consuming that it is utilized for non-food purposes. The research objective was to develop a new technology for processing undersized sea fish into minced ready-to-eat products.
Study objects and methods. The study featured experimental samples of fish mince with texturing agents and food additives vs. control samples of pure fish mince. The experiment involved block-frozen Peruvian anchovy (*Engraulis ringens* L.). The anchovy was minced without pre-defrosting, gutting, or beheading. The experimental and control samples underwent sensory evaluation and were tested for moisture content, water-binding capacity, and rheological properties using a PNDP-penetrometer.
Results and discussion. Adding 3.6% of wheat fiber, ≤ 15% of pea flour, ≤ 10% of textured soy, and 12% of onion improved the sensory and technological profiles of the finished product. The recommended mass fraction of fish in the finished product did not exceed 55%, as a higher amount deteriorated the sensory quality of the product. The textured soy provided the optimal texture. The fish balls were cooked from the fish mince, which were deep-fried in breadcrumbs, received a high score for sensory properties and could be recommended as basis for various formulations.
Conclusion. Minced undersized fish, traditionally used as fertilizers or crude product, proved to be an advantageous semi-finished and ready-to-eat product. The developed technology is relevant for most undersized block-frozen sea fish.

Keywords: Seafood, anchovy, *Engraulis ringens*, processing, undersized fish, rheological properties, fish mince, semi-finished products, water-binding capacity

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INTRODUCTION

Commercial fishing and fish processing is an important branch of global food industry. Until recently, fish processing mainly involved refrigeration, drying, or salting of freshly-caught fish. Canning and other means of preservation expanded the range of fish products and seafood [23]. However, they changed the sensory properties of fish, reduced its nutritional value, and increased the cost.

Most fish consumers prefer fresh fish and seafood to ready-to-eat semi-finished fish products [2]. As a result, the fishing industry is currently facing a serious challenge: fresh fish has to be delivered from the catch to the point of sale as fast as possible and with as little change in its composition as possible.

However, fast delivery is not always possible:

1. Most often, geographical location makes fast delivery of live or fresh fish impossible without additional measures to prevent spoilage [3].

2. Unreliable refrigeration equipment may cause temperature fluctuations in cooling chambers, thus increasing the risk of product spoilage.

3. Enzymes in the fish entrails are highly active. As a result, chilled fish is impossible to refrigerate if ungutted. However, gutting opens the way for pathogenic and putrefactive microorganisms to the internal tissues, which reduces the shelf life [9].

4. Quick freezing requires expensive modern equipment, which significantly increases the cost of the finished product. Moreover, consumers always prefer fresh fish [5].

5. Slow freezing significantly reduces the biological and nutritional value of fish, as well as its sensory properties. Tissues become pale, and the texture turns loose and watery. Defrosted fish loses in weight; its protein structure is irreversibly damaged. After cooking, defrosted fish is always inferior in quality to fresh or chilled fish [4].

6. Delivery and refrigeration of fish from the place of catch to the point of sale and consumption creates poor added value, few jobs, and insignificant positive impact on the economy. However, uncontrolled delivery and distribution of fish opens the way to various forms of violations [6].

Therefore, fish processing industry remains underdeveloped and requires improvement.

To become profitable, fish processing should follow the path of the meat industry and develop more sustainable processing procedures. For instance, the meat-processing industry cannot afford to concentrate solely on fillet production, while sending the rest of the carcasses away for feed purposes or disposal, and this is exactly what happens now in the fish processing industry. As the deficit of dietary protein in the world keeps growing, all available fish and seafood protein must be used for food purposes. Thus, the fish processing industry has no other option but to develop a wide range of profitable, delicious, and nutritious food products [7, 11].

The research objective was to develop a technology for sustainable and waste-free fish processing for food purposes, namely, processing frozen undersized sea fish into minced food products.

In minced food production, the result depends on the right choice of fish raw material, since the tissues of various fish species vary in composition, nutritional value, quantity, as well as a ratio of edible, inedible, and conditionally edible parts. Moreover, different fish sorts have different ratios of proteins, lipids, and moisture [18, 19].

Nevertheless, undersized fish has good prospects for minced food production:

1. Small schooling fish is usually caught in industrial volumes.
2. By-catch of undersized fish makes up a significant proportion of industrial fishing. As fish producers fail to find profitable and sustainable use for it, undersized fish gets processed into fertilizers, fishmeal, feeds for industrially grown fish, and fish oil [25].
3. Undersized fish usually has a uniform biochemical profile, age, size, and ratio of proteins, lipids, and water content [13].
4. As a rule, undersized fish is much cheaper than large fish; therefore, processing that increases the added value is more profitable for the fishing industry.
5. Undersized fish is easier to process into mince, since it does not have to be divided into muscle tissue and bones; in fact, a proper cutting mode makes it possible not to remove bones at all [12].

The present research featured Peruvian anchovy (*Engraulis ringens L.*) [25]. The choice of anchovy for fish mince production was based on the abovementioned reasons, as well as on the need to expand the range of fish-based ready-to-eat products [10, 11].

Fish mince production presupposes grinding of raw materials either in a fish bone separator Neopress or in a cutter.

A separator is a more traditional option for the fishing industry. However, it requires preprocessing, namely gutting and beheading, which is a significant disadvantage of this technology. Moreover, it produces a large amount of non-food waste, which must be disposed of. The yield of mince is about 55–60%, depending on the Neopress mode and the requirements for the mince texture [13].

Neopress processing requires additional equipment to introduce and distribute food additives, e.g. a mixer, lifters for mince carts, etc. Another disadvantage is the prospective disposal or recycling of industrial waste, e.g. skin, bones, etc.

In contrast to separators, a high-speed cutter ensures complex processing and produces meat of required composition [14].

Industrial fish cutters have the following advantages:

1. They can mince frozen fish without prior defrosting, which saves time and production space required for defrosting. As a result, fish is not exposed to additional microbial contamination as it never comes in direct contact with workers' hands. Also, fish does not lose muscle juice during defrosting. In addition, industrial cutters decrease the risk of heating the product during cutting.

2. Necessary additives can be introduced right during cutting, and their distribution is even. In fact, the entire production cycle takes place inside the cutting bowl. The technology requires no additional equipment, e.g. mixers, and reduces the exposure of the mince to microbial contamination and oxidative spoilage, which is inevitable when the mass is overloaded from the Neopress bowl into the mixer [8].

3. Cutters have a very sensitive control of grinding modes. They are also capable of mixing the introduced components without grinding.

4. Cutters produce no by-products that have to be disposed of. When minced together with its own bones, fish becomes fortified with easily digestible calcium.

5. Cutters can adjust the texture of mince. They even make it possible to obtain fish mince with a pattern on the cut side of the frozen block. Patterning looks especially good when the fish raw material is mixed with various components of contrast color, e.g. spices, herbs, eggs, potato, green pea, etc.

Taking into consideration the obvious advantages of this technology, the experiment involved cutting frozen undersized sea fish entirely, without gutting and beheading.

According to the selected technology, the obtained fish mince is a semi-finished product and cannot be sold directly to retail consumers because of its poor sensory properties. The structure and viscosity of the fish mince vary significantly, depending on the fishing season, age, and size of the fish. Therefore, fish mince must be improved with food additives in order to standardize its properties [16].

STUDY OBJECTS AND METHODS

The research featured samples of minced undersized fish without additives (control) and with flour, wheat fiber, textured soy, onion, food dyer, and spices (experimental samples).

The frozen Peruvian anchovy (*Engraulis ringens L.*) was produced by Colanfish S.A.C. (Peru). It was minced using a Talsa 315 cutter (MP-Technologies, Russia). The experimental samples included the following additives:

– pea flour (Specification 10.61.22-696-37676459-2017. Pea flour[I])

– buckwheat and rice flour (State Standard 31645-2012[II]);

– corn flour (State Standard 14176-69[III]);

– wheat fiber Vitacel WF 200 (Germany);

– textured soy Opttema *M*-03 (Ingredienty. Razvitiye Llc, Russia);

– titanium dioxide E171; and

– spices: paprika powder and turmeric powder (Tsarskaya Priprava Llc, Arta Grupp).

The block-frozen fish was stored at –18°C; the temperature in the center of the block was –16°C at the onset of the experiment. The fish was minced into a fine and pasty homogeneous emulsion.

The physical and chemical properties of the fish mince were determined using standard methods. The mass fraction of moisture and dry matter in the fish mince was registered using several methods: the infrared thermogravimetric method in an Evlas-2M moisture analyzer, the thermogravimetric method in an APS-1 dryer (Analit-Servis), and the arbitration method, which involved drying the sample to constant weight in a drying chamber at 102–105°C.

The rheological properties were measured in a PNDP penetrometer according to State Standard R 50814-95[IV].

The water binding capacity was defined in a Benchmark LC-8 laboratory centrifuge. The control and experimental samples (4 g each) were put in a polyethylene test tube with a perforated insert. The latter was placed in such a way as to allow the liquid to drain. The samples were centrifuged for 20 min at 100 s^{-1}. After centrifugation, the weight of each sample was added to the weight of the substances in the separated liquid, which was determined by drying at 105°C to constant mass.

Percentage of bound moisture was calculated according to the following formula:

$$X = \frac{(m_1 + m_3 - m_2) \cdot 100}{m_0} \quad (1)$$

where m_1 is the weight of the sample after centrifugation, g; m_3 is the mass of the dry residue of the released liquid, g; m_2 is mass of dry residue in the sample, g; and m_0 is the weight of the sample before centrifugation, g.

The sensory properties of the fish mince were defined using a five-point tasting expert assessment.

RESULTS AND DISCUSSION

Changing the rheological parameters. Minced food industry uses only frozen fish, since undersized fish quickly deteriorates when heated during cutting. Frozen fish is minced to a fine and pasty homogenous emulsion. As a result, the initial and final viscosity values can be used as limit values applicable in practice [14].

Viscosity largely depends on the temperature, which increases with prolonged cutting. Overheating should be avoided by all means: the fish mince must stay below 0–2°C [21]. Figure 1 shows the effect of temperature on viscosity during cutting. The viscosity was measured when the fish mince started to melt and the ice crystals disappeared. The experiment proved that fish has to stay below –4°C during cutting. The present research presupposed no experiments for temperature above +6°C, since temperature this high is unacceptable for microbiological reasons [22].

As rheological properties are concerned, production of mince from whole fish has to pursue two opposing goals. On the one hand, the cutting should be coarse enough to preserve the natural texture, taste, and texture of the fish. However, a coarsely-minced mass maintains fragments of bones and other inclusions. On the other hand, fine grinding reduces the abovementioned risks and produces a fine and uniform paste, but it is quite fluid because muscle fibers and cell walls were destroyed.

In this research, the fish underwent a fine cutting. The mass acquired the desired texture from dietary fiber, various flours, and textured soy protein. These components are cheap, have a reliable technology, and produce a multifactorial effect on the properties of the product [23].

Wheat fiber bound excess water, fortified the product with fiber, and improved the sensory properties of the finished product. Figure 2 shows how the amount of wheat fiber affected the viscosity of the fish mince.

The wheat fiber proved to be a very effective stabilizer of texture in the amounts between 2.5% and 6%. The wheat fiber introduced at the onset of cutting bound the water that resulted from the

[I] TU 10.61.22-696-37676459-2017. Pea flour.

[II] State Standard 31645-2012. Flour for baby's nutrition. Specifications. Moscow: Standartinform; 2019. 11 p.

[III] State Standard 31645-2012. Corn flour. Specifications. Moscow: Standartinform; 2012. 4 p.

[IV] State Standard R 50814-95. Meat products. Methods of penetration determination by means of the cone and the needle indentor. Moscow: Standartinform; 2010. 8 p.

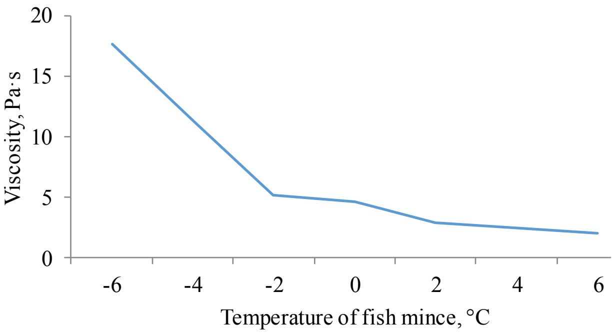

Figure 1 Effect of temperature on viscosity of fish during cutting

destruction of fish tissues. The obtained fish mince was of a medium-dry texture, so that extra water had to be added in a ratio of 2:1 to the fiber weight.

When the fiber was introduced at the final stage of cutting, it was less effective, and the fish mince contained more water. Adding 6% fiber to the fish mass reduced the adhesion of the mince mass to the bowl and to the plastic pads during freezing. However, more than 4.5% of fiber had a negative effect on the taste, adding a blend, "cottony" taste to the finished product.

Wheat fiber products are available in different fiber lengths. Coarse and long fiber proved to be the optimal variant: it was Vitacel WF 200 with the fiber length of 250 μm. Its long fibers served as an additional reinforcing frame for the mince system. The optimal amount was based on economic calculations and technological feasibility: 3.6% of wheat fiber improved the quality of the mince, when introduced at the second stage of cutting, right after table salt (1.3%). A larger amount of fiber impaired the taste of the product and made it crumbly when molded.

Figure 3 shows the results of sensory evaluation of the fish mince samples. The overall sensory quality of the product improved when the amount of fish fell down to 50–55% as it was substituted with onion, pea flour, textured soy, etc. According to the sensory evaluation, the sample with a minimal amount of minced fish tasted better. However, the experts were able to identify the product as fish-based but failed to guess the fish species. The rheological measurements (Table 1) proved that the

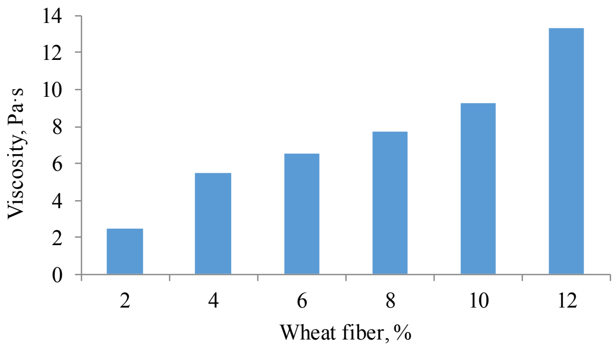

Figure 2 Effect of wheat fiber on viscosity of fish mince

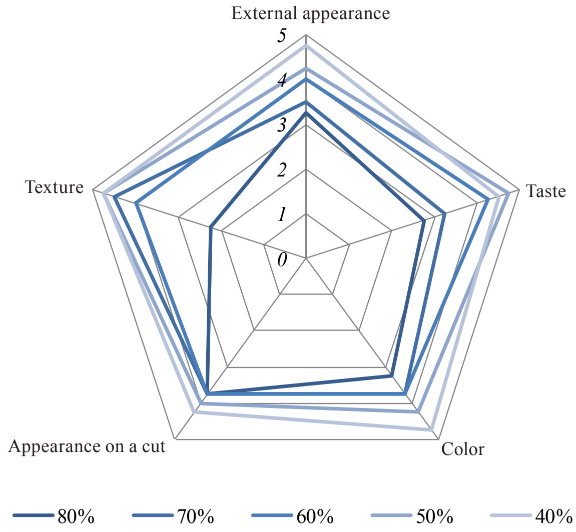

Figure 3 Sensory evaluation of fish mince depending on fish proportion in the product

strength of the sample depended on the mass fraction of the minced fish. A lower mass fraction increased the viscosity and density of the product. Therefore, the mass fraction of fish raw material had to be reduced by introducing various additives. The additives should be cheap and able to improve or, at least, not to spoil the taste of the product. Preference should be given to those additives that have a positive water-binding capacity of at least 1:1 and can improve the nutritional value of the product [16].

The mass fraction of fish could not go below 50%, since such a product would cease to be fish-based.

Additives were introduced at the third stage of cutting, after the texture of the fish mince was stabilized with food fibers. The additives were followed by the same amount of water (1:1) to avoid over-drying. In calculating the mass fraction of the additives, the mass fraction of fish always remained over 55%.

The additives involved rice, corn, buckwheat, and pea flours at the proportion of 5–15% at 2.5 intervals. Figure 4 shows the effect of the mass fraction of the abovementioned plant raw materials on the sensory properties of the samples.

In each case, the plant additives significantly changed the sensory properties, which improved the quality of the semi-finished products. Flour increases the density and texture, as well as the water-retaining

Table 1 Shear stress of fish mince with different mass fraction of fish (*P* > 95, n = 3)

Mass fraction of fish in the sample,%	Max. shear stress, Pa
80	27.8 ± 0.2
70	29.6 ± 0.2
60	35.4 ± 0.3
50	37.2 ± 0.2
40	32.6 ± 0.3

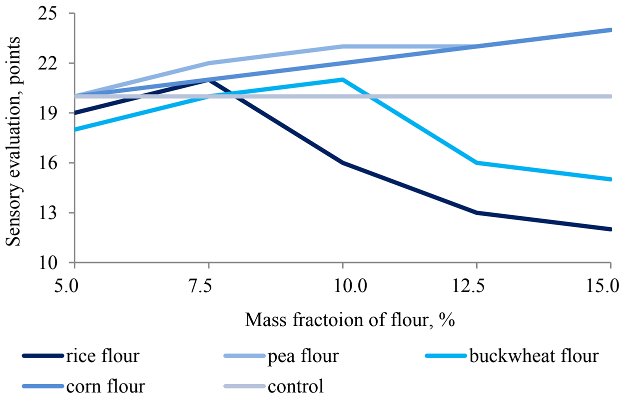

Figure 4 Effect of mass fraction of plant additives on sensory evaluation score of fish mince

and water-binding capacity, and does not affect the typical taste of the product. After the extreme point, the complex sensory index decreased as the properties of the plant component began to prevail. As a result, the product lost its sensory properties. A higher content of flour failed to form a strong structure with the fish component, which decreased the rheological parameters of the semi-finished products at the stage of freezing and subsequent heat treatment.

The effect of the flour mass fraction on the increase in the water-retaining capacity was of complex nature, which could be explained by the high, yet ambiguous water-binding characteristics of the plant ingredients (Table 2). The pea flour demonstrated the most pronounced water-binding capacity, while the rice flour had the lowest index. High water content made the finished product tenderer and increased its economic efficiency.

The rice flour had a low water-retaining capacity (1:0.8). Its amino acid score was also lower than that in the other flours [15]. The buckwheat flour gave the fish product an uncharacteristic color and taste, which makes it unsuitable for such products. The corn flour and the buckwheat flour had equally high water-retaining properties (1:2.2), while the pea flour demonstrated a better amino acid score and proved cheaper [15].

Therefore, the pea flour appeared to be the optimal additive. The amount was calculated for combined use with other ingredients. The sample with a mass fraction of pea flour ≤ 15% showed the best results. The same amount of water was added to hydrate the pea flour. A higher amount resulted in a specific pea taste, which was stronger than the taste of fish.

Flours and dietary fiber made it possible to raise the viscosity of the fish mince to the required level. However, the resulting product had a suspiciously uniform texture without any inclusions on the cut, which became even smoother after heat treatment. As a result, the experts questioned the presence of fish in the product, as nothing in the mince reminded of fish but its taste. The presence of minced fish in semi-finished products, e.g. fish balls, cutlets, fishburgers, etc., is usually quite obvious and marks the product as natural. Any expert would interpret the homogeneous structure of a semi-finished product as a sign of its artificial nature.

Table 2 Effect of the mass fraction and type of flour on water content and water-binding capacity, % ($P > 95$, n = 3)

Additive	Water content, %	Water-binding capacity, %
Rice flour:		
5.0	68.3 ± 0.1	18.3 ± 0.1
7.5	70.6 ± 0.1	18.5 ± 0.1
10.0	72.4 ± 0.2	19.2 ± 0.1
12.5	73.1 ± 0.1	19.8 ± 0.2
15.0	74.4 ± 0.2	20.3 ± 0.1
Pea flour:		
5.0	70.1 ± 0.1	19.4 ± 0.1
7.5	72.5 ± 0.1	21.1 ± 0.1
10.0	74.2 ± 0.1	22.3 ± 0.1
12.5	75.7 ± 0.2	23.0 ± 0.1
15.0	76.6 ± 0.1	24.2 ± 0.1
Buckwheat flour:		
5.0	69.1 ± 0.1	18.3 ± 0.2
7.5	72.1 ± 0.1	19.2 ± 0.1
10.0	73.0 ± 0.1	21.6 ± 0.1
12.5	73.7 ± 0.2	22.7 ± 0.1
15.0	74.2 ± 0.1	23.6 ± 0.1
Corn flour:		
5.0	69.5 ± 0.2	18.7 ± 0.2
7.5	71.0 ± 0.1	18.9 ± 0.1
10.0	72.1 ± 0.2	20.1 ± 0.1
12.5	72.8 ± 0.1	21.1 ± 0.1
15.0	73.6 ± 0.1	22.0 ± 0.1
Control	72.2 ± 0.1	18.6 ± 0.2

The textured soy proved to be the best ingredient that gave the fish mince a non-uniform texture of fish meatballs. Introducing textured soy into the fish mince had the following specifics:

1. The texturing agent should be added after hydration in a ratio of 1:2.2 to water. A larger hydration ratio dissolved the coarse texture.
2. The texturing agent should be introduced at the very last stage of cutting, and the knives should be turned to mixing mode in order to prevent excessive cutting and loss of texture.
3. The texturing agent should not be too dry, since the fish mince has no free water left at the last stage of cutting, and the next stage is refrigeration.

The amount of textured soy depends on the desired properties of the final product. For fish rolls and fishburgers, the experiment delivered the following optimal parameters: 10% of dry texturing agent to the mass of anchovy and 22% of water for its hydration. A smaller amount of hydrated texturing agent did not make the product heterogeneous, while a higher amount made the experts mistake it for artificial.

Changing the color of the minced products. The color of the fish product depends on the properties of the fish itself. When minced, it darkened even more due to

(a) (b)

Figure 5 Samples of fish mince: a – unbleached, b – bleached (titanium dioxide, 0.8%)

the contact of muscle tissue with oxygen. Food pigments and dyes could change the color of fish mince and finished products. Titanium dioxide (E171) was able to bleach the fish mince. It was chosen for its effectiveness and good safety requirements [17, 20]. Depending on the amount, the fish mince acquired different hues of light gray (Fig. 5). The maximal amount was 0.8–1%; a further increase in concentration was inappropriate in terms of color. Paprika and turmeric powder gave the product different hues (Fig. 6).

Color correction was optimal after preliminary bleaching with titanium dioxide E171; if added before bleaching, a much larger amount of dyes and pigments was required.

Changing the taste of the minced products. The experiment featured undersized fish with a low sensory profile, which was minced together with heads and entrails. As a result, the taste indicators of the fish mince samples were in direct proportion to the percentage of the fish in the finished product. With the concentration of minced fish exceeded 55%, the sensory properties decreased, and the taste, color, and texture deteriorated.

Spices, especially dried fried and fresh onion, improved the taste of the finished product, masking the typical taste of cheap fish. The fresh onion provided the best taste and also improved the texture of the fish mince by changing the degree of fineness. Onion bleached the color as the concentration of fish in the sample was lower, and the antioxidants in the onion juice affected the pigments in the tissues of the minced anchovy. Onion also extended the shelf life of the samples as its phytoncides affected the microflora.

The experiment featured several types of onion: dried onion flakes, dried fried onion granules, and fresh onion. On the one hand, such a variety of dried onion is convenient in production. The flakes were easy to store, hydrate, and apply exactly according to the formulation. On the other hand, dried onion was more expensive and had neither antioxidant nor antimicrobial effects. Moreover, it did not lighten the color of the fish mince.

Finally, fresh onion was considered optimal at ≤ 12% to the mass of the raw fish. A larger amount of onion could water in the mince and make it impractical. Onion was introduced before the textured soy to ensure its uniform cutting and distribution.

Fish cutter technology. To avoid excessive temperature rise and oxidation, the cutting time was as short as possible and included the following stages:

1. High-speed cutting of frozen fish in the shortest time possible, preferably under vacuum.
2. Adding sodium chloride and titanium dioxide E171 to bleach the color of the mince.
3. Introducing dietary fiber to bind the water released from the mince, prevent the mince from sticking to the bottom of the bowl, and avoid its overheating.
4. Adding a precalculated volume of water to hydrate the dietary fiber in a ratio of 2:1.
5. Introducing fresh onion.
6. Introducing additives and textured soy hydrated in a ratio of 1:2.2, as well as extra water to hydrate the additives.
7. Adding spices.
8. Ceasing the cutting process before the mass reaches +2°C to prevent its oxidative and microbial deterioration.

(a) (b) (c)

Figure 6 Effect of spices on the color of fish mince: a – bleached (titanium dioxide, 0.8%), b – with 0.8% of paprika, c – with 1.3% of turmeric

Table 3 Microbiological indicators of finished products before cooking

Product	Microbiological indicators: actual content/standard			
	QMAFAnM, CFU/g, ≤	Coliforms	*S. aureus*	Pathogenic, including *Salmonellae* and *Listeria monocytogenes*
Fish bolls	$0.34\times10^5/1\times10^5$	0.0008/0.001	not detected	not detected

9. Molding the fish mince into cutlets or balls.
10. Breading the balls.
11. Freezing or cooking.

The microbiological control showed acceptable amounts of mesophilic aerobic and facultative anaerobic microorganisms (QMAFAnM) and bacteria of the *Esherichia coli* group (Table 3).

CONCLUSION

Cutting proved to be a reliable and efficient technology. The research featured samples of undersized block-frozen sea fish, which appeared to be a perfect raw material for cutter processing. The best results belonged to samples frozen at –6… –4°C without preliminary defrosting or heating.

The optimal rheological and sensory parameters belonged to the samples with mass fraction of dietary fiber = 3.6%, pea flour = 15%, and soy texturing agent = ≤ 15% (hydration level depended on the desired texture). Titanium dioxide E171 (0.8%) bleached the color of the fish mince. Natural spices, food pigments, and dyes gave the samples attractive yellow-red color range. Onion significantly improved the taste of the product. Samples with 12% of onion received the highest sensory evaluation score.

Although the technology was tested on Peruvian anchovy (*Engraulis ringens* L.), it can be applied to most commercial undersized sea fish. This sustainable technology can provide the yield of 130% of fish mince. The recommended mass fraction of fish in the finished product should not exceed 55%, as a higher ratio could spoil the sensory profile of the product.

CONTRIBUTION

I.L. Rakityanskaya supervised the project. A.A. Gorbatovskiy performed the experimental research. A.A. Gorbatovskiy and M.V. Kaledina processed the data and prepared the manuscript.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

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