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DEVELOPING FUNCTIONAL FISH-PLANT SNACKS WITH IMPROVED LIPID COMPOSITION AND PHYSICOCHEMICAL PROPERTIES

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This paper reports the results of a study aimed at devising a technology for producing fish-plant functional snacks. The research focuses on improving the product recipe in order to enhance its organoleptic, physicochemical, and rheological properties, as well as to increase its biological value.

The raw material includes minced mullet (Planiliza haematocheila), fortified with 20% Jerusalem artichoke powder, 0.5% of a 20% sodium alginate solution, and prophylactic salt with reduced sodium content. The effects of these additives on water-holding capacity, physicochemical characteristics, structural and mechanical properties, microbiological stability, and sensory attributes were evaluated. It was found that the addition of Jerusalem artichoke increased the water-holding capacity by 11.7%, while the incorporation of 0.5% sodium alginate solution decreased the yield stress to 8.1 kPa and increased stickiness to 3.2 kPa.

During production and storage, lipid modification processes were observed. The dynamics in accumulating the conjugated dienes and trienes, products of PUFA conjugation, which leads to the formation of additional functional properties, were studied. The peroxide value did not exceed 0.043% I2/100 g of fat, demonstrating high oxidative stability. The shelf life of the dried fish-plant snacks was determined to be up to 25 days when stored at 2–6°C.

The formulation devised demonstrates a strong potential for practical application in the field of functional nutrition, particularly in the production of health-oriented food products and could be implemented in large-scale manufacturing to meet daily physiological nutrient requirements

Keywords: fish-plant snacks, mullet mince, Jerusalem artichoke powder, sodium alginate, rheological properties, oxidative stability of lipids, conjugated dienes and trienes, peroxide value, functional nutrition

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1. Introduction

Nutrition is a key factor affecting a person's health, performance, and overall well-being. The balance of nutrients in the daily diet directly determines the efficiency of physiological processes, supports immunity, and provides the body with energy. The more diverse the diet, the more complete its nutritional value. The optimal diet should include products of both plant and animal origin, which provides the human body with the necessary set of macro- and micronutrients [1].

Fish and seafood play an important role in human nutrition, as they are a valuable source of easily digestible protein, essential amino acids, vitamins, and minerals. They contain omega-3 polyunsaturated fatty acids (PUFAs), which help strengthen the cardiovascular system, increase mental activity, and support the immune system. In addition, PUFAs, under the influence of a number of physical and chemical factors, are able to undergo the process of conjugation of double bonds with the formation of conjugated fatty acids (CFAs). CFAs have a number of functional properties, in particular, they destroy cancer cells by activating the apoptosis process, reduce fat mass in the human body, and help strengthen bones, muscles, and other organs of the musculoskeletal system [2, 3].

In addition, marine fish are rich in iodine, which is an important element for the normal functioning of the thyroid gland. In terms of the content of vitamins PP and B_6, aquatic organisms significantly surpass meat products.

In the modern food industry, dried fish products are gaining particular popularity, which are characterized by a high concentration of biologically active substances and belong to the category of snack products. Given their convenient format and long shelf life, they are an ideal option for people who lead an active lifestyle. Snacks vary in appearance, composition, and production technologies, but their advantage is their readiness for consumption [4].

Taking into account that fish contains a lot of PUFAs, fish snacks can be considered as a source of this important component in its conjugated form [5].

One of the varieties of dried-cured products is fish snacks, which have more pronounced taste qualities compared to chips from plant raw materials, as well as higher biological and nutritional value. For the production of such products, minced fish from aquatic raw materials is used as a basis, to which various components are added that act as flavoring and structure-regulating additives [6].

The use of minced fish in combination with functional components could improve the rheological properties of the product, increase its nutritional value, and ensure optimal texture. Such a technological approach contributes to the creation of a new generation of functional snacks that meet modern requirements for food products, including in combination with inulin [7].

Thus, research into the development of functional fish-plant snacks is extremely relevant; they demonstrate significant potential among a wide range of consumers seeking a balanced and healthy diet.

2. Literature review and problem statement

Modern research is actively tackling the integration of plant raw materials into the composition of fish products to increase their nutritional value and improve functional properties. This approach contributes to the expansion of the range of functional food products that meet current trends in healthy eating.

There are significant prospects for the design of combined fish-plant products that could become an alternative to traditional fish or plant products. Scientific papers emphasize the importance of the choice of ingredients and technologies to ensure the sensory and nutritional characteristics of such products [8]; however, those studies do not consider so-iuy mullet since this fish is characteristic of the northwestern region of the Black Sea and adjacent estuaries.

Studies on the use of legumes and cereals such as lentils, peas, and wheat show that they significantly increase the content of vegetable protein and fiber in minced fish. In [9] it was shown that the combination of minced fish with plant components makes it possible not only to increase the nutritional value but also improve the texture of the product, which makes it more attractive to consumers, especially in the context of dietary nutrition. The cited study investigated the effect of preliminary emulsification of pea and silver carp proteins on the quality of the gel of fish sausages. The results showed that such a combination improves the texture and overall acceptability of the product, but the addition of inulin-containing raw materials was not studied. At the same time, issues related to ensuring the stability of such systems during storage, as well as their oxidative and microbiological stability, remain unresolved. Likely reasons are both objective difficulties associated with the complexity of the biochemical interaction of components of different origins, and economic restrictions on the implementation of energy- and resource-intensive technologies. An option for overcoming these problems is the use of functional additives that could stabilize the structure of the product.

Fish raw materials contain a significant amount of polyunsaturated fatty acids, which can change under the influence of a number of factors. In particular, the process of conjugation of double bonds in the fat molecule with the formation of conjugated dienes and trienes, which have a positive effect on human health [2, 10], but this assumption needs to be tested in practice under the conditions of specific technological parameters.

These acids have a pronounced anticancer effect on cancer cells both in vitro and in vivo in experiments conducted on cell cultures and on animals. This was first discovered by Michael Pariza in 1985 when he studied the properties of an extract from meat products that had undergone heat treatment [11]. The effect of CLA on carcinomas and papilloma in animals, inhibition of tumor growth in the mammary gland, intestine, liver, and other organs [3] was revealed. CLA preparations are widely used to combat fat cells, which is why they are called "fat burners". They contribute to the improvement of the parameters of the human body by increasing muscle and bone mass while simultaneously reducing fat stores. The use of CLA improves the balance of blood plasma lipoproteins, reduces lipid deposition in the aorta, and leads to a decrease in atherosclerotic plaques that are already present in the body.

At the same time, the FDA in 2008 recognized CLA as GRAS [3], that is, a safe substance, the presence of which in the product does not cause any concerns and which could be present in the human diet in any reasonable quantities.

Natural CLA is mainly found in meat, milk, and dairy products of ruminants, mainly cows, sheep, and goats. In lipids of other animals, CLA can be formed during technological processing and storage due to the process of conjugation of PUFAs present in raw materials, including fish lipids. The presence of CLA in muscle products with such a wide range of positive properties for human health allows them to be considered as functional products and recommended for wider use in various population groups [5]. One of the promising ingredients for increasing the biological value of fish-plant snacks is Jerusalem artichoke powder. It contains a significant amount of inulin – a natural prebiotic that helps normalize intestinal microflora, improve mineral absorption, and strengthen the immune system. In addition, Jerusalem artichoke is rich in B vitamins, iron, potassium, and antioxidants, which are important for maintaining cardiovascular health [12].

Despite the promising use of Jerusalem artichoke powder in functional snacks, there are no comprehensive studies in the scientific literature on its effect on the rheological properties of minced fish, structural and mechanical characteristics of finished products, and their sensory qualities. It is also important to study the optimal level of Jerusalem artichoke powder addition to ensure a balanced product composition and preserve its organoleptic properties.

Thus, further research aimed at developing fish-plant snacks using Jerusalem artichoke powder and PUFA conjugation is relevant and promising. It would make it possible to design a product with improved functional properties, which could help meet the demand for healthy nutrition and expand the range of functional snacks. Thus, the unresolved issue is to devise a recipe and technology for the production of snacks based on minced fish fillet – a raw material typical of the northwestern Black Sea region; clarify the impact of inulin-containing raw materials and sodium alginate on the finished product; as well as practically confirm the theoretical possibility of CFA formation from PUFA in minced fish.

3. The aim and objectives of the study

The aim of our work is to design functional fish and vegetable snacks based on minced so-iuy mullet with improved organoleptic, physicochemical, and rheological properties based on studying the influence of functional ingredients (in particular, Jerusalem artichoke powder and sodium alginate), as well as confirm the theoretical assumption of the process of conjugation of fatty acids of fish minced fish during technological processing. This will make it possible to design a functional product with increased biological value, focused on the needs of healthy nutrition, which will contribute to expanding the range of functional snacks and satisfying the growing consumer demand for healthy products.

To achieve this aim, the following objectives were accomplished:

– to investigate the influence of Jerusalem artichoke powder and sodium alginate on the functional, technological, and rheological properties and the formation of the structure of fish and vegetable minced fish;

– to analyze the composition of functional ingredients and assess the degree of satisfaction of the daily physiological need of a person when consuming ready-made snacks;

– to determine the organoleptic characteristics of fish and vegetable snacks;

– to establish the shelf life of the developed snacks, taking into account the lability of lipids in fish raw materials and microbiological safety, and justify storage conditions.

4. The study materials and methods

The object of our study is the technology for producing dried fish and vegetable snacks of functional purpose based on minced fish that are fortified with Jerusalem artichoke powder. The rheological, structural, and organoleptic characteristics, as well as the functional properties of the obtained products were studied.

The principal hypothesis assumes that the addition of Jerusalem artichoke powder and sodium alginate to the minced fish could make it possible to design functional fish and vegetable snacks with improved rheological, physicochemical, and organoleptic properties, as well as high biological value. Since Jerusalem artichoke is a natural prebiotic, its inclusion could increase the nutritional value of the product while sodium alginate would contribute to stability and optimal structure [13].

Assumptions adopted in the work: Jerusalem artichoke powder has a positive effect on the rheological properties of minced fish and vegetables, in particular, it increases its water-holding capacity and ensures the stability of the structure during the drying process. Due to the high content of inulin and other biologically active substances, Jerusalem artichoke contributes to increasing the nutritional value of the product. Its use is consistent with the physicochemical foundations of creating functional products, in particular, due to the effect on moisture-binding properties, acidity, water activity, and structural and mechanical indicators of minced fish. Sodium alginate, as a natural polysaccharide with pronounced gelling properties, contributes to the formation of a stable protein network in the structure of fish and plant minced fish, which improves the texture, increases viscosity, and ensures the structural integrity of the product during drying and storage. This is consistent with the physicochemical foundations of developing functional fish and plant snacks, which take into account the physical and chemical processes that occur during heat treatment and drying. In particular, the texture of the product changes, which is due to protein denaturation reactions and gelation, as well as important parameters such as moisture, pH, fat content and water-holding capacity. This makes it possible to improve the functional properties of the product and ensure its stability and long shelf life [14]. The combination of minced fish with Jerusalem artichoke powder and sodium alginate makes it possible to obtain a product with high functional value. Such a product provides balanced nutrition and could be effective for consumers who need high-quality, healthy, and convenient-to-transport food. It also helps improve the physiological needs of the body under conditions of a limited diet.

Simplifications accepted in the work: our study did not take into account possible changes in the biochemical composition of fish components depending on the source of raw materials (different regions of fish catching).

For the production of experimental samples of fish-plant snacks, chilled fish was used – so-iuy mullet, which met the requirements of current standards. Chilled fish was subjected to inspection, dismemberment into carcasses, and washing. After that, the processed fish was sent to the Neopress VOLTEK SM-300 separator for mechanical separation of muscle tissue from bones and skin with simultaneous grinding ($d = 2 \div 3$ mm). The resulting minced fish was subjected to fine grinding in the Food Processor RCKC-9000 cutter by the Royal Caterin company to a paste-like mass. During the cutting process, Jerusalem artichoke powder TM "Zdorovo", prophylactic salt with a reduced sodium content, and sodium alginate from TOV "Khimsale" were added to the fish raw materials. Alginate was previously dissolved in water at a temperature of 75°C in a ratio of 200 g per 1 l of water. The resulting fish-plant composition was cut into portions weighing $0.5 \div 1$ kg. They were rolled into layers $0.5 \div 1.0$ cm thick and laid out on a baking sheet. Then the blanks were cooled and kept on racks in a refrigerator at a temperature of $0 \div 2$°C for $6 \div 10$ hours. After that, the plates were dried under artificial conditions (infrared drying cabinet – InfraRed Basic 10) at a temperature of 60 ± 2°C. The end of drying was determined by the organoleptic indicators of the dried mass and its moisture content. The dried product should have a dense consistency and a pleasant aroma and taste characteristic of this type of product, without dampness and negative shades. The mass fraction of water in the finished product should be within $18 \div 20$%. Dried fish-plant snacks were stored at a temperature of $2 \div 6$°C and a relative humidity of no higher than 75.0%, optimally within $60.0 \div 65.0$%.

During the study, the mass fraction of moisture was determined by the arbitration method. This method is based on drying samples in a drying oven at a temperature of 150 ± 2°C to constant mass according to DSTU ISO 1442:2005. The protein content was determined according to DSTU 8030:2015. The mass fraction of fat was determined by extracting a pre-dried sample in a Soxhlet extractor according to DSTU ISO 1443:2005. The ash content was determined by burning the sample in a muffle furnace at a temperature of 400°C according to DSTU ISO 936:2008. The amount of inulin was determined after acid hydrolysis of inulin to fructose [15]. The content of mineral substances was determined by atomic absorption method on a Techtron-AA-4 spectrophotometer [16]. The amount of iodine was determined by inversion voltammetry [17].

When determining the water-holding capacity (WHC), a sample of the test sample was placed in a TC-20 MICROmed thermostat (China) with a temperature of 75 ± 1°C and kept for 15 minutes. After that, the sample was transferred to centrifuge meshes and centrifuged for 15 min at 1000 rpm in an OPN-8 centrifuge (TNK "DASTAN"). The supernatant was drained; the test sample was weighed and the WHC was calculated [18].

To determine the structural and mechanical properties of minced fish, a conical plastometer was used to assess the degree of penetration and ultimate shear stress [19]. The test sample of minced fish was placed in the instrument cuvette. The surface of the sample was leveled with a metal ruler so that the minced fish was flush with the edges of the cuvette. The cuvette with the sample was placed on the instrument table and raised until the cone touched the surface. The device was started by turning on the stopwatch and, holding the bar, slowly lowering the cone. During the immersion of the cone, the depth of its immersion was recorded by the indicator every minute. The immersion lasted 3–5 minutes, since at the end of this period the cone sank only to a small depth. The immersion interval from 180 to 300 s corresponded to the maximum relaxation of the minced fish.

To calculate the value of the ultimate shear stress θ (Pa), the following formula was used that depended on the mass and depth of penetration

$$\theta = K \cdot \frac{m_1 + m_2}{h^2}, \text{ Pa}, \quad (1)$$

where θ – ultimate shear stress, Pa; K – constant characterizing the indenter cone; h – immersion depth of the conical indenter, mm; m_1 – total mass of the conical plastometer rod, kg; m_2 – mass of the conical indenter, kg.

The stickiness was determined using the Sokolov-Bolshakov device, which is based on measuring the force required to separate two adhered surfaces of minced fish [19]. Adhesion or sticking was calculated as the specific force of separation of the plate from the minced fish sample according to the following formula

$$\sigma_0 = \frac{F_0}{S_0} = \frac{9.81 \cdot m}{S_0}, \text{ Pa}, \quad (2)$$

where σ_0 – stickiness, Pa, F_0 – tear-off force, N; S_0 – geometric area of the plate, m^2; m – mass of the load, kg.

Organoleptic studies were carried out in accordance with DSTU 8451:2015 by sensory analysis on a five-point scale.

The significance coefficients were determined taking into account the type of product. The highest significance was assigned to consistency (1.00), since it is the texture that is the key criterion for the acceptability of snacks for the consumer as snacks are consumed mainly "by feel": crunchiness, elasticity, brittleness, chewiness – all this is determined by consistency. It has a psychological impact on satisfaction with the product. If the taste is good, but the consistency is "rubbery" or sticky – the product will be perceived negatively. Excessive rigidity or brittleness leads to a decrease in the perception of product quality.

Smell (0.75) has a significant impact on the first impression of a product and its appeal, especially in fish products, where the aroma profile is critically important.

Appearance (0.65) also influences consumer choice, although somewhat less than consistency or smell.

Taste (0.35) has a moderate weight since snacks have a pronounced functional nature and may include additives that affect taste (e.g., Jerusalem artichoke, alginate), so the taste expectations are somewhat different from traditional fish products.

Color (0.25) received the lowest significance since it is not critical for the perception of the quality of snacks, and natural color fluctuations within the permissible range are possible in dried products.

The total coefficient of the organoleptic assessment is 3.0, which is the result of the sum of the coefficients of significance of individual criteria for the acceptability of snacks for the consumer: consistency (1.00), smell (0.75), appearance (0.65), taste (0.35), and color (0.25). The choice of such a sum is a completely conscious and justified step to ensure convenient scaling of weight coefficients in further calculations of the integral assessment. The use of a total coefficient of 3.0 makes it possible to clearly correlate the weights of individual parameters: for example, the weight of consistency could be interpreted as 1/3 of the total value, the weight of smell – as 25.0%, etc.

The significance coefficients were determined on the basis of expert analysis using the paired comparison method, which is a generally accepted methodology in the field of organoleptic assessment of food products. This approach involves comparing each parameter with each other according to the degree of influence on the overall perception of the product and further normalization of the obtained estimates to form weight coefficients. This methodology provides an objective reflection of the relative significance of each organoleptic indicator, taking into account the characteristics of the product and consumer priorities.

The peroxide value is determined by titrating iodine, which is released during the interaction of peroxides present in fats with potassium iodide. The amount of iodine released corresponds to the amount of peroxides in the sample [20].

The content of conjugated fatty acids was determined using ultraviolet spectrophotometry on a Spectrolab UV-1150 UV-Vis spectrophotometer. Lipids were previously extracted from the product with hexane in a Soxhlet apparatus. The content of conjugated dienes was determined at a wavelength of 230.0 ÷ 234.0 nm with an absorption maximum at 232.1 nm. Conjugated trienes were determined by the presence of a triplet in the range of 262.0 ÷ 283.0 nm with an absorption maximum at 266.3 nm [2].

Microbiological studies were conducted in accordance with DSTU 8446:2015, DSTU EN 12824, DSTU 30518-97, DSTU EN 26461-1:2002, DSTU EN ISO 11290-2:2022, and DSTU 8447:2015.

To determine the effect of adding Jerusalem artichoke powder on the functional, technological, and organoleptic properties of fish and vegetable minced fish from so-iuy mullet, the effect of the mass fraction of Jerusalem artichoke powder added on the properties of the resulting system was first studied. For this purpose, special experiments were conducted in which the fish mass was fortified with different amounts of Jerusalem artichoke powder, and the WHC and organoleptic properties of the fish and vegetable composition were determined. Subsequently, based on this mass, experimental samples of functional dried fish and vegetable snacks were produced, their chemical composition was determined, their biological value was calculated, and organoleptic studies were conducted.

5. Results of investigating the influence of plant ingredients on the functional properties and lipid composition of fish snacks

5. 1. Determining the influence of Jerusalem artichoke powder and sodium alginate on the functional-technological and rheological properties of fish and plant minced fish

To establish the influence of Jerusalem artichoke powder on the change in the functional-technological properties of the fish and plant composition (according to the values of WHC), different dosages of the plant additive were added to the obtained fish minced fish samples. Minced fish was prepared using traditional technology. The dosage of the additive was 5; 10; 15; 20; 25; 30% by weight of the minced fish. The amount of Jerusalem artichoke powder within 5.0 ÷ 30.0% by weight of the minced fish was selected experimentally, taking into account the functional-technological objectives of the study. This range of concentrations makes it possible to trace the trends in the change in the water-holding capacity, rheological and organoleptic properties of the fish and plant composition depending on the additive content. The step of 5% was chosen as optimal for registering noticeable changes between the variants without overcomplicating the experiment.

Minced fish with a WHC value of more than 53.0% is characterized by good molding ability, and finished products based on them have high rheological indicators – a monolithic structure and elastic consistency [21]. Studies show that when adding 5.0% of Jerusalem artichoke powder, there was a slight increase in the WHC of the minced fish (by 2.4%) compared to the control sample, the WHC of which was 77.5%. The maximum increase in WHC (up to 90.9%, i.e., by 13.4%) was achieved when adding 20% of the mass of dry Jerusalem artichoke powder to the studied minced fish (Fig. 1). Further increase in the proportion of Jerusalem artichoke powder led to a decrease in the WHC indicator, and the quantitative level did not decrease to the value of the control sample. The decrease in the WHC at high doses of Jerusalem artichoke powder could be explained by physicochemical and structural changes in the system, which lead to less effective water binding with excessive amounts of Jerusalem artichoke powder. The best ratio between Jerusalem artichoke powder and water is achieved in the range of up to 20.0%, after which the addition of more powder may negatively affect the ability of minced fish to retain moisture.

Fig. 1 demonstrates that there is a statistically significant difference between the variants of samples without and with the addition of 20.0% sodium alginate solution at a significance level of $p = 0.05$. This is confirmed by the fact that the difference in the average values of the moisture content retained by the samples (WHC) within each level of the mass fraction of Jerusalem artichoke powder (5.0 ÷ 30.0%) significantly exceeds the corresponding values of the least significant difference ($HIP_{0.05}$), which is 0.34 for factor A and 0.38 for factor B. For example, with a mass fraction of Jerusalem artichoke of 20.0%, the average WHC value was 85.2% for samples without alginate and 90.9% for samples with alginate; therefore, the difference was 5.4%, which significantly exceeds the significance limit.

To improve the rheological characteristics of the minced fish, it was decided to additionally add a special food additive-structure-forming agent to the resulting composition [22–24].

0.5% of a 20.0% solution of sodium alginate was chosen as such an additive, which corresponds to a 0.1% alginate content in the minced fish composition. This mass fraction is sufficient to achieve gelation and improve the structure of the minced fish without undesirable effects on the consistency, organoleptic and chemical properties of the product [22]. Other options were not studied since the goal was to evaluate the effectiveness of alginate as a stabilizer in the minimum required amount, which does not burden the recipe and preserves the naturalness of the composition.

The data obtained showed that the fish-based composition for the production of snacks with the addition of Jerusalem artichoke powder and a 20% solution of sodium alginate has sufficiently high rheological indicators (Fig. 2).

In the studied fish-plant minced fish, SFT was 6.55 ÷ 9.2 kPa (Fig. 2). The smallest SFT value was detera mined in minced fish with the addition of 5.0% Jerusalem artichoke powder, and the largest – with the addition of 30.0%.

According to the stickiness index of fish-plant minced fish compositions, no statistically significant difference was found between the variants with different concentrations of Jerusalem artichoke powder. This is confirmed by the fact that the difference in mean values does not exceed the value of the least significant difference (LSE0.05).

The stickiness values were within 2.75 ÷ 3.2 kPa, with the highest stickiness being in minced fish with 20.0% Jerusalem artichoke powder. Although there is a tendency for stickiness to increase with increasing water-holding capacity (WHC), these differences are not statistically significant at the significance level $p = 0.05$.

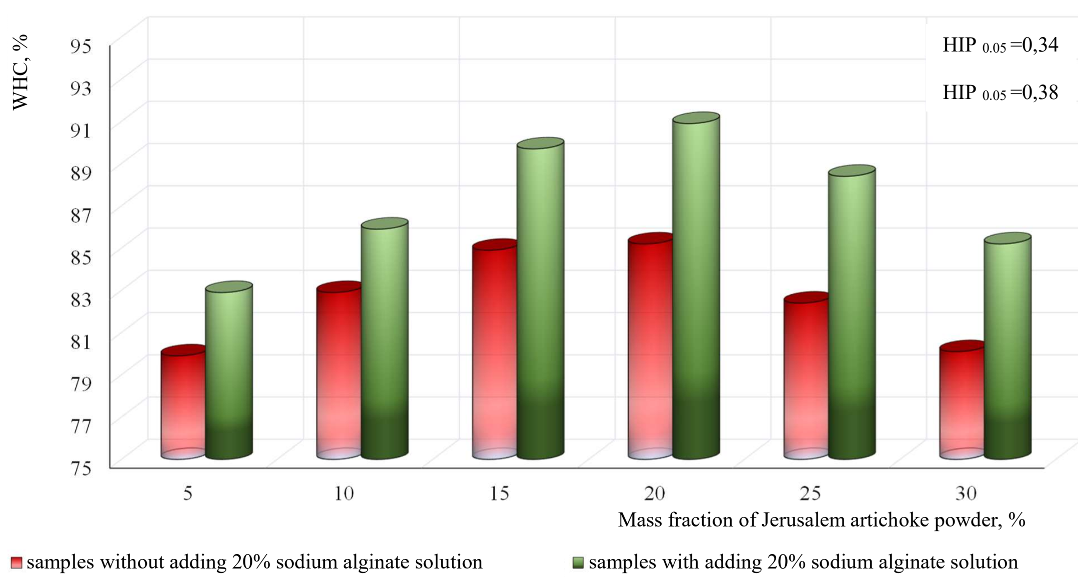

Fig. 1. Effect of Jerusalem artichoke powder and sodium alginate solution on the water-holding capacity of fish and vegetable minced fish

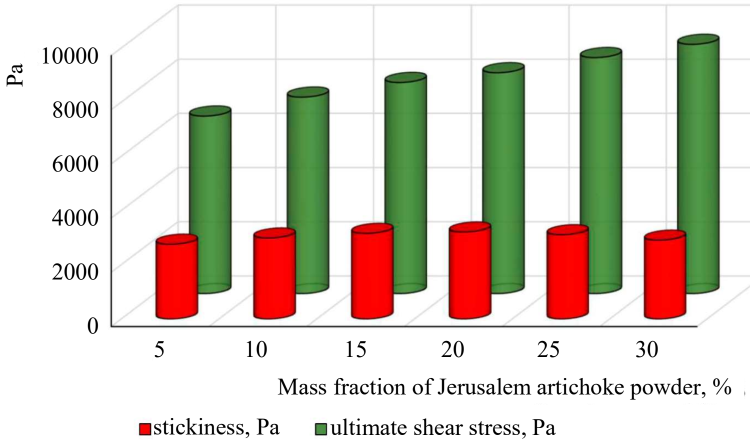

Fig. 2. Effect of Jerusalem artichoke powder and sodium alginate solution on the rheological parameters of fish and vegetable minced fish

The stickiness of the fish-plant minced compositions varied from 2.75 to 3.2 kPa. The highest stickiness was found in minced fish with the addition of 20.0% Jerusalem artichoke powder. The stickiness values are correlated with WHC data – the higher the WHC of the minced fish, the higher the stickiness. A sufficiently high stickiness of minced fish helps fully mold the finished product, which ensures its quick portioning in the production of snacks.

5. 2. Analyzing the composition of ingredients and assessing the degree of satisfaction of the daily physiological need of a person

Taking into account the data obtained, a minced composition for fish-plant snacks was proposed and experimental snack products were produced.

Since dry snacks contain a lot of sodium salts, in order to reduce their negative effect on the human body, ordinary table salt, which contains an increased amount of sodium chloride, was replaced with preventive salt, in which about 30% of sodium chloride was replaced with potassium chloride, magnesium sulfate, and potassium iodate.

Data on the analysis of the chemical composition of experimental snacks compared with control samples are given in Table 1. Dried plates from fish mass were used as controls, without the addition of Jerusalem artichoke, without sodium alginate, and using ordinary table salt.

From the above data it is clear that the introduction of 20% of Jerusalem artichoke powder and the replacement of regular salt with preventive salt contributes to the production of a functional product with inulin content, which provides the degree of satisfaction of the daily requirement for it by 62.7%. In addition, this increases the balance of the mineral composition of the final product. The sodium content decreases, the potassium magnesium and iodine content increases. The iron, copper, and zinc content decreases since these components are contained in fish, and not in Jerusalem artichoke.

The concentration of preventive salt with a reduced sodium content was selected in accordance with the WHO recommendations on reducing sodium consumption for the prevention of cardiovascular diseases, while ensuring a sufficient level of preservation and taste properties of the product.

Table 1

Comparative characteristics of the composition and degree of satisfaction in functional ingredients of human physiological needs when consuming experimental and control snack samples

Indicator ID	Recommended daily intake	Experimental snacks (with Jerusalem artichoke powder, dosage 20%)		Control snacks (without Jerusalem artichoke based on fish mass)	
		Content per 100 g	% satisfaction of physiological daily requirement with the use of 100 g	Content per 100 g	% satisfaction of physiological daily requirement with the use of 100 g
Moisture, g	–	18.0	–	18.0	–
Protein, g	80.0	44.2	55.2	55.2	69.0
Lipids, g	80.0	18.6	23.3	23.3	29.1
Including conjugated fatty acids after 10 days of storage					
CLA, mg	*	9.0	*	8.7	*
CLnA, mg	*	4.3	*	4.2	*
Including conjugated fatty acids after 25 days of storage					
CLA, mg	*	20.1	*	18.7	*
CLnA, mg	*	9.8	*	9.6	*
Inulin, g	15.0	9.4	62.7	0	0
Minerals					
Sodium, mg	5000.0	1207.2	24.1	1509.0	30.2
Potassium, mg	2500.0	2431.2	97.2	1584.0	63.4
Phosphorus, mg	800.0	488.0	61.0	610.0	76.3
Calcium, mg	1200.0	36.0	3.0	45.0	3.8
Iron, mg	10.0 (17.0**)	6.6	66.0 (38.6**)	8.2	82.0 (48.2**)
Magnesium, mg	400.0	102.0	25.5	43.5	10.9
Iodine, mcg	200	120	60.0	80	40.0
Copper, mg	1.0	0.4	40.0	0.5	50.0
Zinc, mg	12.0	0.3	2.5	0.4	3.3

*Note: * – no standard; ** – physiological need for iron for women*

5. 3. Studying the organoleptic indicators of fish and vegetable snacks

The results of sensory analysis are given in Table 2.

Analysis of the results given in Table 2 reveals that both samples of fish and vegetable snacks received high organoleptic ratings, approaching the maximum limit (15.0 points).

At the same time, the sample with the addition of a vegetable component was marked with slightly higher scores, which is associated with its consistency, which more closely matches consumer expectations. In particular, the elasticity characteristic prevailed in the structure of the consistency assessment, which was achieved due to the addition of sodium alginate solution, which positively affected the texture of the finished product.

The color varied from saturated dark red to amber, with a characteristic transparency of an amber shade on the lumen. The consistency of the product was uniform, dense, and elastic, without cracks or surface defects.

For a more detailed analysis of the taste qualities of fish and vegetable snacks, a profile method of sensory evaluation was used, the results of which are shown in Fig. 3.

Table 2

Organoleptic evaluation of ready-made fish and vegetable snacks

Indicator ID	Indicator significance coefficient	Assessment, point			
		Without taking into account the indicator's significance coefficient		Taking into account the coefficient of significance of the indicator	
		Control without adding a plant component	With the addition of a plant component with Jerusalem artichoke powder, dosage 20%)	Control without adding a plant component	With the addition of a plant component with Jerusalem artichoke powder, dosage 20%)
Appearance	0.65	4	5	2.60	3.25
Taste	0.35	5	5	1.75	1.75
Color	0.25	5	5	1.25	1.25
Smell	0.75	5	5	3.75	3.75
Consistency	1	5	5	5.00	5.00
Total Score	3.0	–	–	14.35	15.00

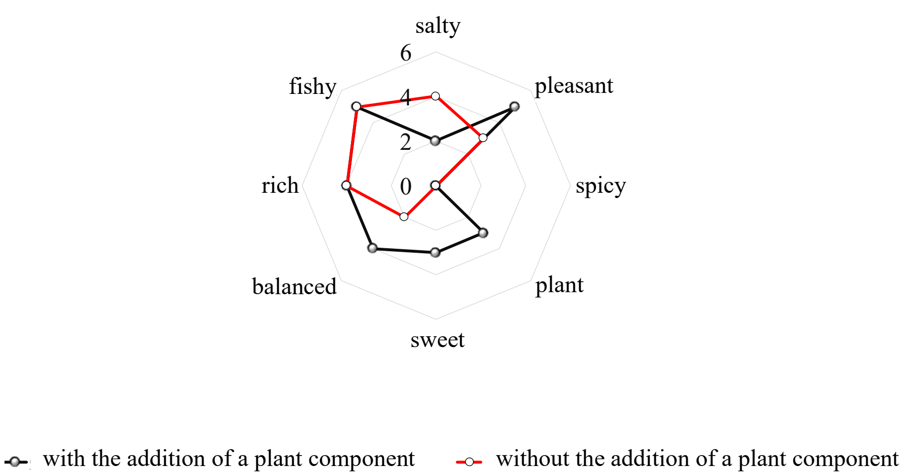

Fig. 3. Flavor profile of fish and vegetable snacks

The data indicate that among the evaluated sensory characteristics, such as "fishy", "pleasant", "balanced", and "rich" flavors dominate. No signs of extraneous, undesirable, or disharmonious sensations were recorded. In the control sample, sweetness was less pronounced, and saltiness was more pronounced. Since fish is the main component in both samples, the fishy taste is nevertheless highly pronounced. The presence of vegetable flavor as a result of the addition of Jerusalem artichoke powder did not lead to a decrease in the "pleasant" taste; on the contrary, this indicator became greater. The balance of taste increased due to the addition of the vegetable component. Thus, the rational dosage of Jerusalem artichoke powder, introduced at the stage of formation of the fish-plant mass, could be 20%. This amount of vegetable additive makes it possible to obtain minced fish that meets the required characteristics in terms of its texture and rheological properties, while achieving the functionality of the product in terms of the content of biologically active substances and high organoleptic indicators.

5. 4. Determining the shelf life of the devised fish and vegetable snacks

When substantiating the shelf life of the devised products, we proceeded from the results of analyzing the dynamics of the entire complex of basic quality indicators during storage. To establish the shelf life of dried fish and vegetable snack products based on minced fish from so-iuy mullet and Jerusalem artichoke powder, the microbiological and organoleptic indicators of the product were studied during storage at a temperature of 2 ÷ 6°C and a relative humidity of not more than 75.0%.

Changes in the values of microbiological indicators of functional dried fish and vegetable snacks based on minced fish from so-iuy mullet fortified with Jerusalem artichoke powder are given in Table 3.

From the data in Table 3 it follows that when storing the studied snacks for 25 days at the specified temperatures, there is a tendency to accumulate general non-pathogenic microorganisms (QMAFAnM) and molds. At the same time, there are no *Escherichia coli*, *Staphylococcus aureus*, pathogenic microorganisms, *L. monocytogenes* and sulfide-reducing clostridia.

It was found that the organoleptic indicators of fish-plant snacks analyzed during storage changed slightly and met regulatory requirements even on the 25th day. Another important factor affecting product quality is the accumulation of fat oxidation products (in the presence of a fat fraction). The dynamics of the accumulation of peroxide value in lipids of the developed fish-plant snacks during storage at the above temperatures are shown in Fig. 4.

Data in Fig. 4 demonstrate that within 30 days the accumulation of peroxides in experimental samples of functional dried fish and vegetable snacks based on minced fish from so-iuy mullet, fortified with Jerusalem artichoke powder, does not exceed the value of 0.043% I_2/100 g of fat. This level is safe and corresponds to the recommended one for functional fish snack products. The addition of Jerusalem artichoke powder leads to the production of dried minced products that are well stored and do not lead to premature oxidation of lipids. The data obtained correlate well with the literature [25].

Taking into account the above data, the shelf life for functional dried fish and vegetable snacks at a storage temperature of 2.0 ÷ 6°C is set at 25 days.

The study of changes in the content of conjugated dienes and trienes in lipids of fish and vegetable snacks from minced fish from so-iuy mullet and Jerusalem artichoke powder during storage is illustrated in Fig. 5.

Table 3

Dynamics of microbiological indicators for dried fish-plant snacks from minced so-iuy mullet with the addition of Jerusalem artichoke powder during storage ($t = 2.0 \div 6.0$°C; $\varphi \leq 75.0\%$)

Indicator ID	Rated value	Storage duration, days				
		0	15	20	25	30
QMAFAnM, CFU/g, not more	Not exceeding $5 \cdot 10^4$	$1.7 \cdot 10^2$	$6.5 \cdot 10^2$	$1.4 \cdot 10^3$	$2.3 \cdot 10^3$	$5.3 \cdot 10^4$
BGCP (coliforms)	Not allowed per 0.1 g	n/d	n/d	n/d	n/d	n/d
Pathogenic, including salmonella	Not allowed per 25 g	n/d	n/d	n/d	n/d	n/d
L. monocytogenes	Not allowed per 25 g	n/d	n/d	n/d	n/d	n/d
Sulfite-reducing clostridia	Not allowed per 1 g	n/d	n/d	n/d	n/d	n/d
Molds	Not exceeding 50 CFU/g	12	19	37	42	58
Yeast	Not exceeding 100 CFU/g	n/d	n/d	n/d	n/d	n/d

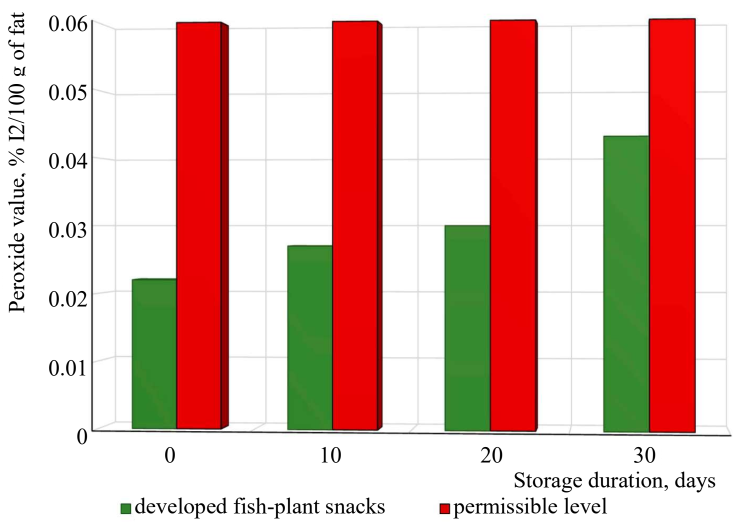

Fig. 4. Dynamics of peroxide accumulation in lipids of fish-plant snacks based on minced so-iuy mullet and Jerusalem artichoke powder during storage

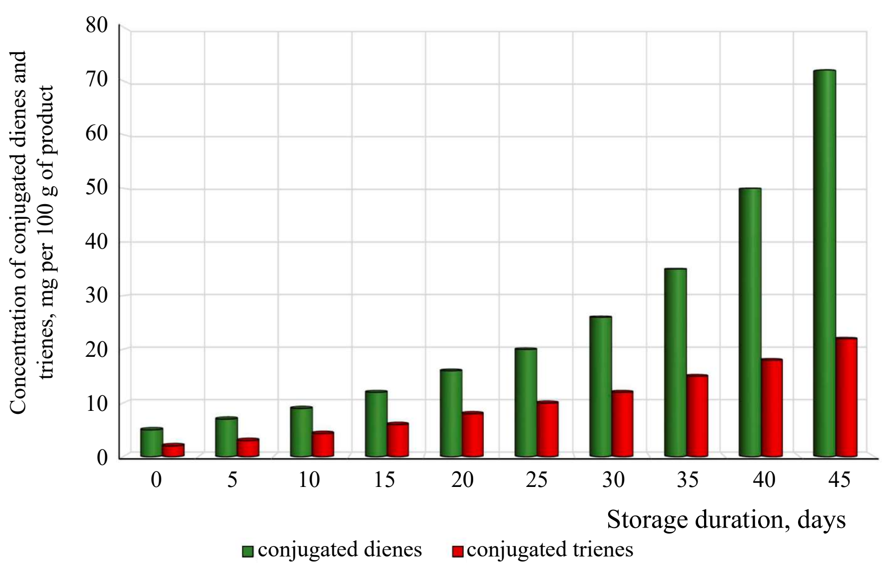

Fig. 5. Dynamics of accumulation of conjugated dienes and trienes in lipids of fish-plant snacks based on minced so-iuy mullet and Jerusalem artichoke powder during storage

From the data in Fig. 5 it is clear that during the storage of snacks from minced so-iuy mullet, the process of fat modification occurs with the formation of conjugated dienes and trienes due to the conjugation of double bonds in polyunsaturated fatty acid (PUFA) molecules. In this case, fatty acids with isolated double bonds undergo restructuring, i.e., those that are separated from each other in the carbon chain by no less than two single bonds. Fish lipids contain a large percentage of PUFA with isolated double bonds. The formation of conjugated linoleic acid (CLA) and conjugated linolenic acid (CLnA) is most likely.

In the product immediately after drying, the content of conjugated polyenes is low, which indicates that heat treatment in the range of 60°C does not lead to the formation of a significant amount of this component.

The accumulation occurs precisely during the storage of snacks; the accumulation becomes especially noticeable after 30 days of storage.

The presence of conjugated dienes and trienes in snacks allows us to consider them as a product fortified with biologically active substances that enhance its functional properties.

6. Discussion of results based on investigating the influence of plant ingredients on the functional properties and lipid composition of fish snacks

During our study, it was found that the introduction of Jerusalem artichoke powder into the composition of fish raw materials has a significant impact on the functional and technological properties of model minced fish compositions. This also improves the organoleptic characteristics, chemical composition, and the degree of satisfaction of the physiological need of humans in biologically active components.

Studies have shown that the introduction of Jerusalem artichoke powder into the composition of fish raw materials significantly affects the water-holding capacity of minced fish. The highest indicator of WHC (90.9%) was recorded at a dosage of 20% Jerusalem artichoke powder (Fig. 1). A further increase in the proportion of Jerusalem artichoke to 25.0% led to a decrease in WHC to 88.4%, at 30% powder – 85.2%, which indicates the presence of an optimal dosage at the level of 20.0% (Fig. 1).

It was found that the shear stress threshold (SST) of minced fish increases with the introduction of Jerusalem artichoke. When adding 5 ÷ 30% of Jerusalem artichoke powder, the value of shear stress threshold (SST) increased from 6.55 to 9.2 kPa (Fig. 2). The increase in SST indicates a decrease in plasticity, probably due to the binding of water by the minced fish components. Water from free water passes into bound water and cannot perform the function of a so-called "lubricant" between the product layers. This demonstrates that an increase in the content of the plant component increases the elasticity of the minced fish mass and reduces plasticity. If the minced fish is formed in the form of plates, they will retain their shape better and spread less on the plane. The data obtained correlate with studies on the rheological parameters of combined meat-vegetable minced fish [26].

Organoleptic evaluation (Table 2) confirmed that the most favorable in terms of consumer properties are samples with a content of 20% Jerusalem artichoke powder.

These compositions are characterized by good plasticity (Fig. 2), a pronounced fishy taste with a pleasant sweetish tint (Fig. 3), due to the inulin content, as well as good ability to be formed into plates – an important property for snack-type products. This fully correlates with the results in terms of WHC, which for the specified samples ranged within 85.2 ÷ 90.9% (Fig. 1), confirming the ability of the selected additives to improve the technological performance of the product. These indicators indicate the achievement of an optimal balance between the structure-forming properties of the protein matrix of fish raw materials and Jerusalem artichoke powder.

The study of stickiness, as another criterion of technological suitability of minced fish, revealed the highest value – 3.2 kPa in the sample with 20% Jerusalem artichoke powder (Fig. 2), while the lowest value – 2.75 in samples with 5% Jerusalem artichoke powder. Thus, the high stickiness of minced fish provides high cohesion and lack of brittleness, minced fish is strong and not brittle, it does not crumble into particles. In combination with the absence of spreading, this determines the good preservation of the shape and integrity of the finished product. An important factor that affects the above properties is sodium alginate.

An important factor examined in our study was the use of a 20% sodium alginate solution as a structure stabilizer. Sodium alginate is a natural polysaccharide with high gelling ability [27], and its addition at a concentration of 0.5% contributed to strengthening the structure of the minced mass, improving stability during heat treatment and drying. It also allowed us to form a consistency characteristic of traditional fish snack products. Due to the ability of alginate to form gels in the presence of calcium ions, better stabilization of the minced matrix is achieved [28]. This is especially important in combination with Jerusalem artichoke powder, which has a limited ability to form a protein network. Sodium alginate compensates for this deficiency, increasing the consistency and elasticity of the product.

Based on the studied indicators, a recipe for experimental snacks was devised, which additionally includes preventive salt with a reduced sodium content, which makes it possible to consider the product in the category of functional food products. The reason for using this additive instead of regular salt is the high content of sodium chloride in snacks and the low content of such vital elements as potassium, magnesium, and iodine (Table 1).

Assessment of the chemical composition of experimental and control snacks (Table 1) makes it possible to draw a number of important conclusions regarding the functional potential of the product. First of all, it is worth noting that the fortification of the composition with Jerusalem artichoke had a positive effect on the carbohydrate profile – inulin appeared in the amount of 9.4 g per 100 g of product, which satisfies 62.7% of the recommended daily requirement. Inulin as a prebiotic is a key factor in the formation of a healthy intestinal microbiota, therefore, its presence in the composition of snacks indicates a high nutraceutical value of the product [29]. The PUFA present in fish raw materials undergo a conjugation process during storage, which leads to the accumulation of CLA and CLnA in the product (Fig. 5), which have a positive effect on human health. Exact standards for the required amount of conjugated fatty acids in the human diet have not been developed; therefore, it is not possible to determine the degree of satisfaction of the physiological daily requirement. In the process of further research, it will be useful to establish factors that could accelerate the process of formation of CLA and CLnA in the product.

Experimental snacks are a good source of potassium, magnesium, and iodine. Increasing the iodine content makes it possible to normalize the state of the thyroid gland [30].

Organoleptic evaluation (Table 2) confirmed the high consumer appeal of the product. Harmonious taste notes prevailed without signs of undesirable or foreign flavors (Fig. 3). A feature of the developed snacks is the combination of classic fish characteristics with a weakly pronounced sweetish vegetable shade, which provides novelty and originality of the taste. The results of the tasting analysis indicate a successful technological combination of ingredients and the correct selection of their dosage. In particular, 20% of Jerusalem artichoke powder content turned out to be optimal for achieving the necessary plasticity, density, and uniformity of minced fish, as well as for maintaining high organoleptic properties.

Microbiological studies of the developed fish-plant snacks (Table 3) indicate high microbiological stability of the product during the first 25 days of storage at a temperature of 2.0 ÷ 6°C. Analysis of QMAFAnM indicators demonstrates a gradual increase in the total number of mesophilic aerobic and facultative anaerobic microorganisms from $1.7 \cdot 10^2$ CFU/g on the first day to $2.3 \cdot 10^3$ CFU/g on the 25th day. However, on the 30th day the indicator exceeds the maximum permissible values, which indicates the end of the safe storage period.

The key point is the absence of such pathogenic microorganisms as *Escherichia coli*, salmonella, *Listeria monocytogenes*, sulfite-reducing clostridia, as well as yeast during the entire storage period under study. This indicates an adequate level of hygienic safety in the production of the product and the effectiveness of the applied temperature treatment and drying parameters. The appearance of mold fungi after the 25th day in an amount exceeding the norm (over 50 CFU/g) limits the product's consumption period to 25 days without additional preservation methods.

The peroxide value, which is an indicator of the oxidative stability of lipids, in the samples studied during 30 days of storage did not exceed the value of 0.043 mg I_2 per 100 g of fat (Fig. 4). Such a low level of peroxide indicates sufficiently high stability of the lipid component. This is probably achieved due to the low residual moisture after drying, which inhibits the processes of enzymatic oxidation under the influence of the lipoxygenase enzyme. Oxidation under the influence of both organic and inorganic factors is additionally inhibited by the low storage temperature and the absence of light.

Our study confirms the feasibility of using Jerusalem artichoke powder as a promising ingredient for creating functional snacks based on fish raw materials. The rational combination of components ensures not only the technological efficiency of production but also the high biological value of the finished product, which is especially important for consumers focused on healthy nutrition. This approach contributes to the formation of a new generation of functional products that meet modern requirements for nutritional quality through the use of raw materials containing functional components, namely, Jerusalem artichoke powder contains the prebiotic inulin, preventive salt contains potassium and magnesium salts.

However, along with positive changes, there are negative ones. The developed product contains less iron, copper, and zinc compared to the control (Table 1). The reason is the reduction in the mass fraction of fish muscle tissue in the recipe, which is a source of these metals, due to its replacement with Jerusalem artichoke powder, which contains very little of these components. This requires further research and development of products that would be devoid of these shortcomings.

However, when moving from laboratory research to production under real conditions, there may be a need to adjust the data obtained: during scaling, new factors that were not taken into account during laboratory research may come into play.

7. Conclusions

1. Our studies have confirmed that the addition of Jerusalem artichoke powder and sodium alginate to minced fish significantly affects its physicochemical and structural-mechanical properties. The optimal dosage was determined to be 20%, which provides a maximum increase water-holding capacity up to 89.2%. The stickiness of the minced fish changes insignificantly; thus, there is no need to change the snack formation modes.

2. The production of fish-plant snacks based on minced fish from Jerusalem artichoke with the addition of Jerusalem artichoke powder provides increased biological value of the product, which makes it promising for use in special and functional nutrition diets. Studies on the chemical composition of experimental snacks showed a significant increase in the content of inulin, potassium, magnesium, and iodine compared to control samples. In particular, the inulin content in snack products reached 9.4 g per 100 g of product, which provides 62.7% of the daily physiological need. During the storage of snacks, natural fats of the raw material are modified due to the process of conjugation of PUFA with the formation of CLA and CLnA, which leads to the emergence of additional functional properties of the product.

3. Organoleptic studies showed the high quality of the developed fish-plant snacks. Samples with the addition of 20% Jerusalem artichoke powder and sodium alginate solution received the highest scores for taste, texture, and appearance. The product had a dense, elastic consistency, and a harmonious taste profile without foreign shades, which confirms the positive effect of plant components on sensory properties.

4. Studies on the dynamics of microbiological indicators of dried fish-plant snacks from minced so-iuy mullet with the addition of Jerusalem artichoke powder during storage showed the absence of pathogenic microflora during the first 25 days, which meets the hygienic requirements for finished products. Analysis of the accumulation of peroxide compounds in lipids revealed a low level of peroxide value (not higher than 0.043 mg I_2/100 g of fat), which indicates the oxidative stability of the fat phase of the product. Thus, the formation of conjugated dienes and trienes is not accompanied by oxidative spoilage of the product. Taken together, these results confirm the microbiological safety and lipid stability of the developed product during 25 days of storage at a temperature of 2–4°C.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study, as well as the results reported in this paper.

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Data availability

All data are available, either in numerical or graphical form, in the main text of the manuscript.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

References

1. Yaroslavska, L., Zahorodnii, V. (2020). Problems of healthy eating of the youth. Innovations and Technologies in the Service Sphere and Food Industry, 1, 73–81. Available at: https://www.journals.chdtu.ck.ua/index.php/itsf/article/view/30
2. Sels, B., Philippaerts, A. (Eds.) (2014). Conjugated Linoleic Acids and Conjugated Vegetable Oils. Catalysis Series. https://doi.org/10.1039/9781782620211
3. den Hartigh, L. (2019). Conjugated Linoleic Acid Effects on Cancer, Obesity, and Atherosclerosis: A Review of Pre-Clinical and Human Trials with Current Perspectives. Nutrients, 11 (2), 370. https://doi.org/10.3390/nu11020370
4. Fitri, N., Chan, S. X. Y., Che Lah, N. H., Jam, F. A., Misnan, N. M., Kamal, N. et al. (2022). A Comprehensive Review on the Processing of Dried Fish and the Associated Chemical and Nutritional Changes. Foods, 11 (19), 2938. https://doi.org/10.3390/foods11192938
5. Wang, J., Han, L., Wang, D., Li, P., Shahidi, F. (2020). Conjugated Fatty Acids in Muscle Food Products and Their Potential Health Benefits: A Review. Journal of Agricultural and Food Chemistry, 68 (47), 13530–13540. https://doi.org/10.1021/acs.jafc.0c05759
6. Dorozhko, V. V. (2020). Suchasni tekhnolohiyi vyrobnytstva rybnykh snekiv. The XII International Scientific and Practical Conference «Goal and the role of world science in life». Stockholm, 227–228.
7. Burcu, O., Meltem, S. (2018). Effects of Jerusalem Artichoke Powder and Sodium Carbonate as Phosphate Replacers on the Quality Characteristics of Emulsified Chicken Meatballs. Korean Journal for Food Science of Animal Resources, 38 (1), 26–42. https://doi.org/10.5851/kosfa.2018.38.1.026
8. Nowacka, M., Trusinska, M., Chraniuk, P., Piatkowska, J., Pakulska, A., Wisniewska, K. et al. (2023). Plant-Based Fish Analogs – A Review. Applied Sciences, 13 (7), 4509. https://doi.org/10.3390/app13074509
9. Zhou, X., Zhang, C., Zhao, L., Zhou, X., Cao, W., Zhou, C. (2022). Effect of Pre-Emulsion of Pea-Grass Carp Co-Precipitation Dual Protein on the Gel Quality of Fish Sausage. Foods, 11 (20), 3192. https://doi.org/10.3390/foods11203192
10. Kim, J. H., Kim, Y., Kim, Y. J., Park, Y. (2016). Conjugated Linoleic Acid: Potential Health Benefits as a Functional Food Ingredient. Annual Review of Food Science and Technology, 7 (1), 221–244. https://doi.org/10.1146/annurev-food-041715-033028
11. Pariza, M. W., Hargraves, W. A. (1985). A beef-derived mutagenesis modulator inhibits initiation of mouse epidermal tumors by 7,12-dimethylbenz[a]anthracene. Carcinogenesis, 6 (4), 591–593. https://doi.org/10.1093/carcin/6.4.591
12. Chauhan, D. S., Vashisht, P., Bebartta, R. P., Thakur, D., Chaudhary, V. (2025). Jerusalem artichoke: A comprehensive review of nutritional composition, health benefits and emerging trends in food applications. Comprehensive Reviews in Food Science and Food Safety, 24 (1). https://doi.org/10.1111/1541-4337.70114
13. Abka-khajouei, R., Tounsi, L., Shahabi, N., Patel, A. K., Abdelkafi, S., Michaud, P. (2022). Structures, Properties and Applications of Alginates. Marine Drugs, 20 (6), 364. https://doi.org/10.3390/md20060364
14. Kang, Z.-L., Wang, T., Li, Y., Li, K., Ma, H. (2020). Effect of sodium alginate on physical-chemical, protein conformation and sensory of low-fat frankfurters. Meat Science, 162, 108043. https://doi.org/10.1016/j.meatsci.2019.108043
15. Simonovska, B. (2000). Determination of Inulin in Foods. Journal of AOAC INTERNATIONAL, 83 (3), 675–678. https://doi.org/10.1093/jaoac/83.3.675
16. Abbey, L., Glover-Amengor, M., Atikpo, M. O., Atter, A., Toppe, J. (2016). Nutrient content of fish powder from low value fish and fish byproducts. Food Science & Nutrition, 5 (3), 374–379. https://doi.org/10.1002/fsn3.402
27. Tomčík, P., Bustin, D. (2001). Voltammetric determination of iodide by use of an interdigitated microelectrode array. Fresenius' Journal of Analytical Chemistry, 371 (4), 562–564. https://doi.org/10.1007/s002160101010
18. Vinnikova, L. G., Pronkina, K., Kyshenya, A. (2015). Improving efficiency of the dry protein preparations hydrated with the electro activated water. Ukrainian journal of food science, 3 (2), 216–224.
19. Tsykhanovska, I., Skurikhina, L., Evlash, V., Pavlotska, L. (2018). Formation of the functional and technological properties of the beef minced meat by using the food additive on the nanopowder basis of double oxide of two- and trivalent iron. Ukrainian Food Journal, 7 (3), 379–396. https://doi.org/10.24263/2304-974x-2018-7-3-4
20. Mahato, A., Chatterjee, P. N., Sarkar, S., Sen, A. R., Pal, A., Roy, S., Patra, A. K. (2024). Effects of Chemically and Green Synthesized Zinc Oxide Nanoparticles on Shelf Life and Sensory Quality of Minced Fish (Pangasius hypophthalmus). Foods, 13 (17), 2810. https://doi.org/10.3390/foods13172810
21. Qiao, M., Zhang, T., Miao, M. (2024). Minced Beef Meat Paste Characteristics: Gel Properties, Water Distribution, and Microstructures Regulated by Medium Molecular Mass of γ-Poly-Glutamic Acid. Foods, 13 (4), 510. https://doi.org/10.3390/foods13040510
22. Nykyforov, R., Korenets, Y., Frolova, N., Kuzmin, O. (2019). Determination of the effect of calcium chloride on sodium alginate on the restructuring of fish products. Ukrainian Food Journal, 8 (3), 584–596. https://doi.org/10.24263/2304-974x-2019-8-3-14
23. Sow, L. C., Toh, N. Z. Y., Wong, C. W., Yang, H. (2019). Combination of sodium alginate with tilapia fish gelatin for improved texture properties and nanostructure modification. Food Hydrocolloids, 94, 459–467. https://doi.org/10.1016/j.foodhyd.2019.03.041
24. Cevik, M., Icier, F. (2019). Characterization of viscoelastic properties of minced beef meat thawed by ohmic and conventional methods. Food Science and Technology International, 26 (4), 277–290. https://doi.org/10.1177/1082013219888300

25. Zhu, Y., Guo, L., Tang, W., Yang, Q. (2020). Beneficial effects of Jerusalem artichoke powder and olive oil as animal fat replacers and natural healthy compound sources in Harbin dry sausages. Poultry Science, 99 (12), 7147–7158. https://doi.org/10.1016/j.psj.2020.08.058
26. Merenkova, S. P., Zinina, O. V., Khayrullin, M. F., Bychkova, T. S., Moskvina, L. A. (2020). Study of the rheological properties of meat-vegetable minces. IOP Conference Series: Earth and Environmental Science, 613 (1), 012078. https://doi.org/10.1088/1755-1315/613/1/012078
27. Qin, Y., Zhang, G., Chen, H. (2020). The applications of alginate in functional food products. J. Nutr. Food Sci, 3 (1), 100013. Available at: https://www.henrypublishers.com/henry-journal-of-nutrition-and-food-science/jnfs-10011.pdf
28. Qin, Y., Jiang, J., Zhao, L., Zhang, J., Wang, F. (2018). Applications of Alginate as a Functional Food Ingredient. Biopolymers for Food Design, 409–429. https://doi.org/10.1016/b978-0-12-811449-0.00013-x
29. Anderson-Dekkers, I., Nouwens-Roest, M., Peters, B., Vaughan, E. (2021). Inulin. Handbook of Hydrocolloids, 537–562. https://doi.org/10.1016/b978-0-12-820104-6.00015-2
30. Laurberg, P., Nøhr, S. B. (2002). Iodine intake and prevention of thyroid disorders: surveillance is needed. Medical Journal of Australia, 176 (7), 306–307. https://doi.org/10.5694/j.1326-5377.2002.tb04424.x