The effect of cellulose- and lipid-containing components on the technological parameters of the extruded mixture based on protein- and starch-containing raw materials on the technological parameters of the extrudate was studied. The use of components that modify such technological indicators of the extruded mixture as water resistance and swelling is substantiated. It is proposed to use sunflower husks and sunflower phosphatide concentrate as modifying additives to the mixture for extrusion. A rational ratio of the specified components in the extrudate was established to obtain indicators of water resistance in the range of 220...300 min and swelling in the range of 100...120 %. This is an important aspect of expanding the range of extruded products from the waste of oil and fat industries and obtaining high-quality competitive products.

The object of the study is the dependence of water resistance and swelling of the extruded mixture on the content of modifying additives. Their rational ratio in the extrudate is: sunflower husk – 6.0 %; sunflower phosphatide concentrate – 5.0 %. The manufactured extrudate sample corresponds to commercial fish feed in terms of chemical composition and technological parameters, and also has a 4 times lower cost. A feature of the obtained results is the possibility of regulating the water resistance, swelling and porosity of the extrudate based on protein- and starch-containing raw materials, depending on the ratio of cellulose- and lipid-containing modifying additives. This allows to change the technological parameters of the finished product depending on the chemical composition of the mixture of raw components according to the requirements of the consumer. The results of the conducted research prove that cellulose- and lipid-containing secondary products of production can be successfully transformed into new competitive products

Keywords: vegetable extrudate, cellulose-containing components, lipid-containing components, sunflower husk, sunflower phosphatide concentrate

UDC 504.062:665.11: 639.3
DOI: 10.15587/1729-4061.2024.301843

DETERMINATION OF THE CELLULOSE- AND LIPID-CONTAINING COMPONENTS INFLUENCE ON THE EXTRUDATE TECHNOLOGICAL INDICATORS

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Received date 19.01.2024
Accepted date 08.04.2024
Published date 30.04.2024

How to Cite: *Petik, I., Litvinenko, O., Stankevych, S., Zabrodina, I., Ponomarova, M., Kotliar, O., Kliuchko, R., Myhalenko, O., Pidpala, T., Danylchuk, G. (2024). Determination of the cellulose- and lipid-containing components influence on the extrudate technological indicators. Eastern-European Journal of Enterprise Technologies, 2 (6 (128)), 6–13. https://doi.org/10.15587/1729-4061.2024.301843*

1. Introduction

Extrusion is a well-known technological process that allows to get textured proteins of vegetable origin. The advantage of this technology is a radical change in the structure of the raw material, its physical properties and nutritional value, as well as the chemical composition during processing [1]. A wide range of types of plant raw materials are subjected to

extrusion: grain, beans, fruits, vegetables, tubers, leaves and stems of plants, as well as their mixtures [1, 2].

In the process of extrusion, plant raw materials undergo a number of physical and chemical changes and changes in nutritional value. They include oxidation of fats, denaturation of protein, formation of crosslinks of proteins with other substances, gelatinization and dextrinization of starch, destruction of vitamins and carotene, denaturation of enzymes, change in the structure (consistency), color and smell of the product [3, 4]. In addition, the selection of rational parameters of the extrusion process can solve two more important tasks: the destruction of anti-nutrients (protease inhibitors, etc.) contained in some types of plant raw materials and the destruction of pathogenic microorganisms [5].

A promising raw material for vegetable extrudates is the waste of oil and fat production due to its diverse chemical composition and low cost. At the same time, it remains important to determine the risks of impact on the environment [6, 7], pollution of surface and artesian waters [8, 9], and atmospheric air [10, 11]. This especially applies to the production of refined oil, as well as to the waste of oil and fat production in combination with the waste of the fat processing plant [12]. An important advantage of extrusion technology is the possibility of processing waste from the oil and fat industry, such as meal and cakes of oil raw materials, husk, etc., with the aim of their further inclusion in the composition of food products [13]. As a result of extrusion, the finished product expands and acquires a porous structure, which is a positive effect for the finished product [14]. Important technological indicators of extrudates, in addition to porosity [1, 2], are water absorption and the degree of swelling, which characterize the ability of the components of the extruded product to interact with water. Water absorption characterizes the ability of extrudate components, in particular starch and food fibers, to bind with water. Swelling is an indicator of the amount of soluble components of the extrudate (polysaccharides), which are released from it when excess water is added [15, 16].

Since the influence of the input parameters on the raw materials in the extrusion process is complex, it is quite difficult to determine which parameters change changes the specific properties of the extrudate. A reliable determination of the relationships between the input parameters of the process and the output properties of the finished products is complicated by the great variety of types and mixtures of plant raw materials. Also, chemical components of plant raw materials during extrusion under the influence of high temperatures and pressure can enter into chemical reactions with each other, forming complex complexes [2, 17].

Thus, studies devoted to the influence of the characteristics of plant raw materials on the expansion of the range of consumer characteristics of extrudates are relevant and timely, since there is a need to develop an assortment of competitive extrudates with given properties according to consumer requests.

2. Literature review and problem statement

In the study [18], it was established that the low moisture content of raw materials leads to a decrease in the solubility of protein in pea extrudate. It was determined that at optimal humidity during protein denaturation, the degree of its hydrophobicity changes, which allows its molecule to form a three-dimensional structure with high water absorption capacity and low solubility. The solubility of the protein plays an important role in its emulsifying properties, accelerating the diffusion of the protein on the surface of the product, which lowers the surface tension. But the question of the complex effect of proteins and lipids on the chemical composition and technological properties of extrudates remained undefined. This aspect is partially illuminated in the paper [19], the influence of lipids on the features of extrusion of plant raw materials was investigated. It was determined that lipids have a positive effect on the preservation of proteins during the extrusion process, contributing to the reduction of friction, thus plasticizing the finished product. However, a lipid content of more than 5–6 % is undesirable, as it slows down the extruder and impairs the extrusion process. The torque of the extruder screw decreases due to increased friction of the product, and the porosity of the extrudate also decreases. In the study, the issue of lipid oxidation in the processing process remained undefined, as it is known that this process deteriorates the properties of lipid-containing products [20, 21]. The answer to this question is given in work [22], the results of which show that during extrusion the phenomenon of oxidation is not observed due to the short duration of the process. In addition, during extrusion, oxidative enzymes are destroyed and protein-carbohydrate complexes are formed, which have an antioxidant effect.

In the described studies, it remained unclear how the extrusion process affects the lipid content of the final product. This issue was revealed in the study [23], where it was proven that the process of extruding plant raw materials leads to a decrease in the fat content in the finished product due to the formation of lipid-amylose and lipid-protein complexes. It was established that the fat content decreased when the moisture content of the raw material for extrusion (mixture of wheat and almond flour) increased from 26 to 30 %. The question of how this process is affected by the content of starch in the starting mixture remains unresolved, because it is known that in the process of extrusion, starch contributes to good expansion of the extrudate [1, 2]. This aspect is covered in [24]. It was determined that during extrusion starch significantly changes its structure, depolymerization and dextrinization processes take place in it. The effect of high temperature destroys the structure of starch molecules and intermolecular hydrogen bonds. As a result, starch gets the opportunity to absorb moisture more. Due to a sharp pressure drop during the exit of the extrudate from the extruder die, moisture evaporates, which contributes to the formation of the necessary structure of the extrudate. It remains unclear how the modification of starch is affected by the content of another plant polysaccharide – cellulose. Peculiarities of the influence of the dietary fiber content on the technological characteristics of extrudates are described in the study [25], where it was proven that the dietary fiber content as a result of extrusion at temperatures of 100–125 °C does not decrease due to their resistance to its action. At the same time, work [26] established that due to extrusion at temperatures higher than 160 °C, the content of dietary fibers in wheat bran increased. This can be explained by the formation of their complexes with other polysaccharides, in particular starch (amylose fraction).

In the described studies [18–26], the question of the influence of the chemical composition of the raw material on such technological indicators of extrudates as porosity, water absorption, and swelling ability remained unsolved.

Research [27] demonstrates that during the extrusion of corn kernels and mango peel, the maximum linear expansion, that is, the porosity of the extrudate, was observed at a low moisture content of 15.5 % of the extrudate and a screw rotation frequency greater than 100 min^{-1}. In addition, a correspondence was found between high humidity, low process temperature and low porosity of pea extrudate [28]. The obtained result is explained by the fact that high humidity reduces the viscosity of raw materials, which negatively affects material friction and starch pasteurization. This effect is enhanced at low process temperature, which is accompanied by low pressure in the extruder body. The consequence of this is a small pressure drop at the exit from the extruder die and a weak expansion of the extrudate. In the study [29], it was proven that a decrease in the porosity of the plant extrudate is observed in the case of an increase in the moisture content of the raw material from 12 to 17 %. In addition, it was determined that an increase in the content of protein and dietary fibers in vegetable raw materials increases the hardness and density of the extrudate, and a decrease in their content leads to a crisper and softer extrudate. The obtained data are explained by the fact that an increase in the moisture content of plant raw materials leads to a decrease in the viscosity of starch, which limits the formation of gas bubbles and increases the density of the extrudate due to the weakening of the starch structure. In these studies, the dependence of the complex influence of such chemical components of raw materials for extrusion as proteins, lipids, starch and cellulose on the technological parameters of the extrudate is not determined. This issue is partially covered in work [30], where the approximate dependence of the ratio of protein- and starch-containing raw materials on the porosity of the extrudate is determined. Also, in [31], the complex content of lipids and moisture in plant raw materials on the porosity of finished products was determined.

The influence of the chemical composition and extrusion parameters on the ability to absorb water and swell the extrudate is described in works [32, 33]. The moisture content of the raw materials and the temperature of the process have the main influence on the values of water absorption and swelling for vegetable extrudates. In the study [32], a trend of increased water absorption and reduced swelling of rice extrudates was observed when the moisture content of raw materials increased from 12 to 18 %. An excess of water in the raw material increases the water absorption of the extrudate and reduces the viscosity of the starch, which enhances its pasteurization and ensures uniform mixing of the components in the extruded product. In addition, the amount of water absorption and swelling of the extrudate is influenced by the content of food fibers in the raw material. It has been proven that the amount of water absorption of the extrudate increases when the pectin content increases [33]. In addition, the reason for the increase in the amount of water absorption is the destruction of starch grains in the product, while its decrease is associated with a decrease in the content of starch and the formation of complexes of starch with cellulose.

Considering the research results [18–33], it is possible to single out an unsolved problem in the field of food chemistry of plant extrudates. This is the disclosure of the complex influence of the chemical composition of the raw plant material on the technological indicators of extrudates. The specifics of the processes that occur during the modification of the specified chemicals and how they affect the technological indicators of the finished products have not been determined. The specified unresolved aspects create prospects for further research in the outlined area and expanding the understanding of the peculiarities of extrusion processes and its influence on the characteristics of plant extrudates.

3. The aim and objectives of the study

The aim of the study is to determine the influence of cellulose- and lipid-containing components on the technological parameters of the extruded mixture based on protein- and starch-containing raw materials. This will make it possible to expand the range of use of plant extrudates by varying the ratio of components. Also, the obtained data will be useful for increasing the economic efficiency of production and reducing the costs of purchasing raw materials for the production of extruded feed.

To achieve the aim, the following objectives are solved:

– to investigate the chemical composition of additives to plant extrudate, which will allow modification of its technological properties in the direction of increasing water resistance and reducing the degree of swelling;

– to determine the rational content of the specified modifying additives in the vegetable extrudate;

– to determine the influence of the chemical composition on the technological indicators in the developed vegetable extrudate, as well as in the commercial analog - fish feed.

4. Materials and methods of the study

4. 1. Object and hypothesis of the study

The object of the study is the chemical composition of vegetable extrudate based on cellulose- and lipid-containing waste from oil and fat industries. The main hypothesis of the study is the possibility of ensuring the necessary technological characteristics of the extrudate due to the inclusion in the basic composition (oilseed meal and oat groats) [30] of such modifying additives as sunflower husks and sunflower phosphatide concentrate.

The following assumption was made in the study: combining cellulose- and lipid-containing wastes of oil and fat industries in the composition of protein- and starch-containing raw materials will ensure the specified technological properties of the extruded mass, in particular, water resistance and swelling.

In the study, the following simplification was adopted: different batches of sunflower husk and sunflower phosphatide concentrate have similar indicators of the chemical composition of the samples, which were investigated in the work. This should ensure the possibility of repetition of the determined regularities during the combination of other batches of oil and fat industry waste.

4. 2. Researched materials and equipment used in the experiment

The following materials and reagents were used during the research:

– sunflower husks (produced in Ukraine), according to DSTU 7123 (CAS 0011132-73-3);

– sunflower phosphatide concentrate (produced in Ukraine), according to DSTU 4526 (CAS 3436-44-0);

– sunflower meal (produced in Ukraine), according to DSTU 4638 (CAS 68937-99-5);

– soybean meal (produced in Ukraine), according to DSTU 4230 (CAS 68308-36-1);

– crushed oat groats (produced in Ukraine), according to DSTU 7698 (CAS 97-56-3).

4. 3. Fish feed extrusion technique

Extrusion of a pre-ground and homogenized mixture of meal, oat groats, sunflower husks and phosphatide concentrate was carried out on a PE-20 press-extruder (manufactured in Ukraine) according to [30].

4. 4. Methods of determining the chemical composition and technological indicators of raw materials for extruded feed

The following indicators are defined in additives for modifying the technological properties of extruded feed and in the finished product:

– mass fraction of moisture and volatile substances – according to DSTU 7621,

– mass fraction of crude protein – according to DSTU 7169,

– mass fraction of lipids and fiber – according to DSTU 7491,

– mass fraction of carbohydrates – according to DSTU ISO 6493,

– mass fraction of ash – according to DSTU ISO 5984,

– porosity – according to [30],

– water resistance and swelling – according to DSTU 3526.

4. 5. Research planning and results processing

Two-factor experiments were used to determine the influence of the content and ratio of sunflower husk and sunflower phosphatide concentrate on the water resistance and swelling of the extruded mass. Each experiment was repeated three times. The equation of data dependencies was calculated using the approximation of experimental data by constructing a trend line. Processing of experimental data and construction of graphical dependencies was performed using the software package Stat Soft Statistica v 6.0 (USA).

The significance of the coefficients of the approximation equations of the dependences of water resistance and swelling of the extruded mass on the ratio of sunflower husk and sunflower phosphatide concentrate was proven by testing the hypothesis of the equality of the zero parameters of the equation. The degree of influence of the content and ratio of sunflower husk and sunflower phosphatide concentrate on the water resistance and swelling of the extruded mass was evaluated by analyzing the coefficient of determination R^2. The values of R^2=0.961 and 0.975 allow to draw a conclusion about the influence, greater than 95 %, of variations in the content of modifying additives in the extruded mass on variations in its water resistance and swelling, respectively. The significance of the created approximation models was determined by comparing the calculated Fisher criterion with its critical tabular value (F_{tab}(2, 12)=3.88) at the significance level p=0.05 and the corresponding number of degrees of freedom. The calculated values of the Fisher test were:

– for approximation dependence (1): F (2, 12)=16.462,

– for approximation dependence (2): F (2, 12)=21.280.

The obtained results make it possible to recognize the calculated coefficients of determination for approximation dependencies (1) and (2) as significant, and their equations as significant with a probability of more than 95 %.

5. Results of determining the effect of cellulose- and lipid-containing components on the technological parameters of the extruded mixture

5. 1. Research of the chemical composition of the components that modify the technological properties of the extrudate

The chemical composition of experimental samples of cellulose- and lipid-containing waste from oil and fat production was determined: sunflower husks and sunflower phosphatide concentrate, selected as additives that modify the technological properties of plant extrudate (water resistance and swelling). The initial composition of the extrudate, which is proposed to be modified, was developed in a previous work [30]. The results of the determination are presented in Table 1.

Table 1

Chemical composition of samples of cellulose- and lipid-containing components selected to modify the technological properties of plant extrudate

The name of the raw material	Mass fraction, %					
	moisture and volatile substances	crude protein	lipids	fiber	carbohydrates	ash
Sunflower husks	10.70±0.32	0.83±0.02	2.18±0.08	53.70±2.10	4.24±0.17	3.62±0.12
Sunflower phosphatide concentrate	0.68±0.02	0.22±0.01	35.50±1.39	–	–	0.25±0.01

According to the research results, the experimental samples of raw materials selected for the modification of the technological properties of the plant extrudate of the composition substantiated in the study [1] meet the requirements established in the relevant regulatory documentation – DSTU 7123 (CAS 0011132-73-3), DSTU 4526 (CAS 3436 -44-0).

5. 2. Determination of the rational content of modifying additives in vegetable extrudate

To determine the rational concentrations of sunflower husk (c_{sh}) and sunflower phosphatide concentrate (c_{sfc}) in the vegetable extrudate composition described in the study [30], the following dependencies were determined:

– water resistance (WR (c_{sh}, c_{sfc}), %) of the extruded mass from the content of the indicated components;

– swelling (SW (c_{sh}, c_{sfc}), %) of the extruded mass from the content of the specified components.

Equations (1) and (2) describe approximate dependences of water resistance and swelling of the extruded vegetable mixture on the content of sunflower husk (c_{sh}, mass fraction) and sunflower phosphatide concentrate (c_{sfc}, mass fraction):

$$WR\left(c_{sh},c_{sfc}\right)=15.7065+9.3462\cdot c_{sh}-10.7821\cdot c_{sfc}- \\ -0.4565\cdot c_{sh}^2+5.4014\cdot c_{sh}\cdot c_{sfc}+4.0208\cdot c_{sfc}^2, \quad (1)$$

$$SW\left(c_{sh},c_{sfc}\right)=231.0863-10.4371\cdot c_{sh}-10.7292\cdot c_{sfc}+ \\ +0.3516\cdot c_{sh}^2-0.175\cdot c_{sh}\cdot c_{sfc}-0.3646\cdot c_{sfc}^2. \quad (2)$$

The surfaces of the obtained dependences of water resistance and swelling of the extruded vegetable mixture on the content of sunflower husk and sunflower phosphatide concentrate are presented in Fig. 1, 2.

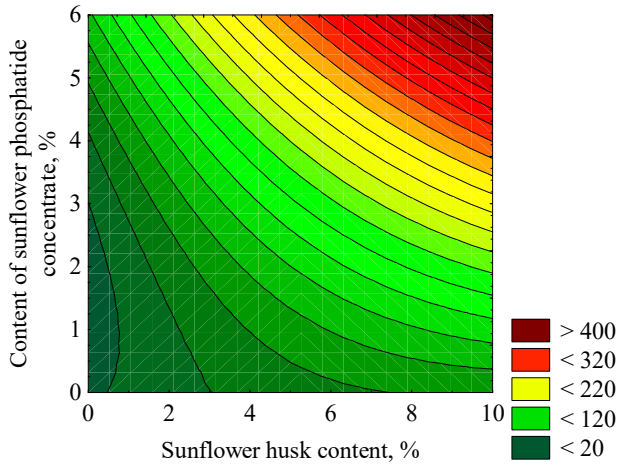

Fig. 1. Dependence of the water resistance of the extruded mass on the ratio of sunflower husk and sunflower phosphatide concentrate in it

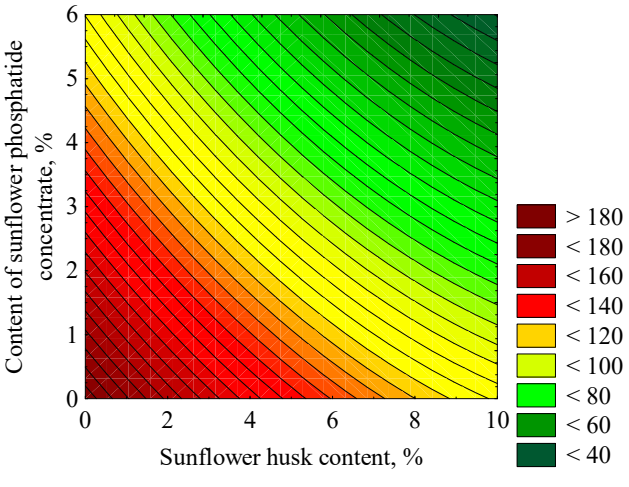

Fig. 2. Dependence of the swelling of the extruded mass on the ratio of sunflower husk and sunflower phosphatide concentrate in it

It should be noted that the approximate dependences (1), (2) adequately describe the water resistance and swelling of the extruded vegetable mixture in the ranges of ratios of sunflower phosphatide concentrate – 0...6 % and sunflower husk – 0...10 %. In this way, the range of the content of the specified raw components, in which the water resistance of the extruded mass is 220...300 min., and the swelling capacity is 100...120 %, is outlined:

– sunflower husks – 3.0...8.0 %;

– sunflower phosphatide concentrate – 3.0...6.0 %.

Based on the obtained research results, an extrudate of the composition described in [1] was produced, containing cellulose- and lipid-containing additives to modify the technological properties:

– sunflower husks – 6.0±0.3 %;

– sunflower phosphatide concentrate – 5.0±0.2 %.

5. 3. Determination of the influence of the chemical composition on technological indicators in the developed plant extrudate and in the commercial analogue

The chemical composition and a number of technological parameters of the developed plant extrudate and commercial feed for fish of the extruded Roycher Aqua Carp Finish of the trademark " Roycher Aqua Fish" [34], which was chosen as a comparison sample, were determined. The composition of the feed, declared by the manufacturer: dehydrated chicken meat meal, fish meal, dehydrated chicken blood, animal fat, fish oil, fodder yeast, wheat, corn, soybean meal, vitamin and mineral premix. The cost of the commercial product is about 1055 USD/t [34]. The chemical composition of the investigated samples of extruded feed is given in Table 2.

Table 2

Indicators of the chemical composition and technological indicators of the developed extrudate and commercial analog

Composition	Extrudates	
	Developed	Commercial analogue (control sample)
Mass share of moisture and volatile substances, %	7.53±0.30	8.15±0.33
Mass fraction of crude protein, %	27.56±1.10	25.60±1.00
Mass fraction of lipids, %	7.84±0.30	8.10±0.30
of them phospholipids, %	3.10±0.12	0.43±0.01
Mass fraction of fiber, %	11.75±0.35	2.42±0.07
Mass fraction of ash, %	4.49±0.13	7.65±0.23
Porosity, %	64.00±1.95	60.00±2.40
Water resistance, min.	265.00±8.00	212.00±8.50
Swelling, %	115.00±3.50	120.00±5.00

Based on the obtained results, the indicators of the chemical composition and technological indicators of the developed plant extrudate are not inferior to the commercial analogue – extruded feed for fish, produced using raw materials of animal origin. The cost of the developed extrudate is about 261 USD/t [1, 35, 36]

6. Discussion of the results of determining the influence of cellulose- and lipid-containing components on the technological parameters of the extruded mixture

The possibility of modifying the technological indicators of plant extrudate based on protein- and starch-containing raw materials (sunflower and soybean meal and oat groats) was investigated. Cellulose- and lipid-containing raw materials (waste from oil and fat production, namely sunflower husks and sunflower phosphatide concentrate) were used as modifying additives. Cellulose- and lipid-containing modifying additives were chosen for reasons of greening of oil and fat production and resource saving.

According to the data in the Table 1, sunflower phosphatide concentrate is a significant source of lipids (99.97 %), including biologically valuable phospholipids (64.30 %). Sunflower husk contains a significant amount of fiber (53.70 %). The obtained results can be explained by the peculiarities of the extraction and refining technologies of sunflower oil, which is associated with the formation of a significant

amount of food-valuable waste. The specified features of the composition of additives are used to regulate the technological characteristics of the extruded mixture, in particular, increasing water resistance and swelling, as well as reducing porosity.

As a result of studies of such technological indicators of the extruded mixture as water resistance and swelling, their dependences were modeled (equations (1), (2) Fig. 1, 2) for a range of ratios of modifying additives:

– sunflower husks (0...10 %);

– sunflower phosphatide concentrate (0...6 %). This allows to justify the range of ratios of modifying additives, in which the water resistance of the extrudate is 220...300 min., and the swelling capacity is 100...120 %. The obtained indicators meet the requirements for extruded fish feed (Table 2). The obtained results indicate that there is an optimal combination of components to achieve the desired technological characteristics of the extrudate. This can be explained by changes in the microstructure and chemical properties of the mixture when these components are added. In particular, the addition of phosphatide concentrate as an emulsifier can also affect the structure, size and distribution of particles in the extrudate.

According to the research results (Table 2), the sample of the extruded mixture of the modified composition practically does not differ from the sample of commercial extruded feed in terms of moisture content (7.53 % and 8.15 %, respectively). The slightly lower moisture content in the test sample can be explained by the fact that the determination of this indicator took place on the day of production of the extrudate. The crude protein content of the extruded mixture is slightly (about 7 %) higher than that of the commercial analogue (27.56 % and 25.60 %, respectively). The lipid content in the experimental sample is somewhat lower (about 3 %). But the content of biologically and technologically valuable phospholipids in the lipid fraction of the extrudates exceeds that in the commercial sample by more than 7 times (3.10 % versus 0.43 %). In terms of fiber content, the experimental sample also exceeds the commercial analogue (11.75 % versus 2.42 %). It is satisfactory for feeding herbivorous fish (fathead minnow) and fish that consume both plant and animal food (carp). It should be noted that the ash content of the developed extruded mixture is lower than the commercial analogue by 41 %, which is also explained by the use of vegetable raw materials. The technological indicators of the manufactured extrudate are not inferior to the commercial analogue:

– porosity – 64 % versus 60 %;

– water resistance – 265 min. against 212 min.,

– swelling – 115 % versus 120 %.

Comparing the indicated indicators of the developed extrudate and the commercial analogue (Table 2), equality was proven according to the determined indicators of its nutritional and technological characteristics. In addition, the cost of the developed extruded feed is 4 times lower than the cost of a commercial analogue, which indirectly indicates the competitiveness of the development. The indicated advantages are explained by the use of cheap vegetable raw materials with a high content of nutrients (protein, lipids, starch), namely waste from oil and fat production.

The development has certain differences from [32, 33], where the one-factor influence of other indicators of the chemical composition on the technological indicators of the extrudate, in particular the moisture content of the raw material, the content of protein and pectin, is determined. The complex influence of the ratio of protein- and starch-containing raw materials on the technological indicators of the extrudate was disclosed in [30], the technological indicators of this development were modified in this study due to the study of the complex influence of cellulose- and lipid-containing modifying additives. Thus, the fairly high content of crude protein in the developed extrudate – 27.56 % (Table 2) is realized due to the presence of protein-containing plant components (soybean and sunflower meal), which have a significantly lower cost compared to raw materials of animal origin. In addition, the water resistance and degree of swelling of the developed extrudate are provided by additives of oil and fat production waste, which also makes the final product cheaper. At the same time, the chemical composition of the raw material, its ratio, and the characteristic technological properties of the products after the extrusion process are predicted.

It is appropriate to outline the conditions of application of the obtained results. Research results must be compatible with existing technological processes and production capabilities, as well as meet consumer requirements for product quality, safety, and efficiency. The results obtained in the course of research open up new opportunities for the effective use of cellulose- and lipid-containing wastes from the production of oils and fats, such as phosphatide concentrate and husks, in extrusion technology. In particular, the results of the work shown in Fig. 1, 2, as well as approximation dependencies (1) and (2) are a scientific work that should contribute to the rational use of phosphatide concentrate and sunflower husk. Such application is expedient in the technology of extruded feeds, provided that it is reasonably combined with protein- and starch-containing components.

The limitation of the use of the research results is that cellulose- and lipid-containing raw materials with certain compositional parameters were used during extrusion: the content of moisture, crude protein, lipids, fiber, carbohydrates, and ash (Table 1). Therefore, in the case of transfer of the method in the production of extrudates based on raw materials of a different composition, it is necessary to take into account the need to adjust the indicators of the chemical composition and technological indicators (porosity, water resistance, swelling) of the finished extrudate.

The lack of information about the effect of changing the extruder parameters on the process of extrusion of mixtures of different chemical composition can be considered a drawback of the study. During the experiment, the temperature in different zones of the extruder and the speed of rotation of the screws were fixed at a certain level.

It is important to note the potential ways of using cellulose- and lipid-containing waste from oil and fat production as a valuable raw material for the production and modification of the technological properties of extrudates. This is, first of all, the enrichment of the obtained extrudates with a complex of micronutrients (vitamins, minerals, etc.) and the study of the degree of their preservation during the influence of the actual extrusion process.

7. Conclusions

1. The chemical composition of cellulose- and lipid-containing additives to vegetable extrudate based on protein- and starch-containing raw materials, which allow modifi-

cation of its technological properties for use in fish farms, was studied. The chemical composition (content of moisture, crude protein, lipids, fiber, carbohydrates and ash) of modifying additives was determined. Modifying additives (sunflower husks and sunflower phosphatide concentrate) meet the requirements established in the relevant regulatory documentation – DSTU 7123 (CAS 0011132-73-3), DSTU 4526 (CAS 3436-44-0).

2. The rational content of sunflower husk and sunflower phosphatide concentrate in the extrudate was established, using approximate dependences of water resistance and swelling of the finished product on the ratio of modifying additives. Their reasonable ratio is: sunflower husk – 6±0.3 %; sunflower phosphatide concentrate – 5±0.2 %.

3. The developed extrudate meets the parameters of the chemical composition of commercial fish feed. According to technological indicators, the product is not inferior to its analogue in terms of porosity (64 % and 60 %, respectively), water resistance (265 min. and 212 min., respectively), swelling (115 % and 120 %, respectively). The cost of the developed extrudate is significantly lower than the commercial analogue (261 USD/t and 1055 USD/t, respectively).

Conflict of interest

The authors declare that they have no conflict of interest in relation to this study, including financial, personal, authorship, or any other, that could affect the study and its results presented in this article.

Financing

The study was conducted without financial support.

Availability of data

The manuscript has no associated data.

Use of artificial intelligence

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

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