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DETERMINING THE EFFECT OF RAW MATERIALS MOISTURE AND LIPID CONTENT ON THE TECHNOLOGICAL PROPERTIES OF THE EXTRUDED PROTEIN-FAT SYSTEM

The way to solve the problem of correcting technological indicators, in particular porosity and moisture content, in extruded protein-fat systems based on soybean, rapeseed, hemp meal, and corn grits is considered. The peculiarity of the work is the substantiation of the rational ratio of the content of moisture and lipids in the raw components of the extrudate, which is an important aspect of rationalizing the composition and improving the texture of innovative extruded products based on the specified raw materials.

The object of the research is technological indicators, in particular the porosity and moisture content of the extruded protein-fat system, depending on the moisture and lipid content in the raw components. A rational ratio of moisture content (10.5...12.5 %) and lipids (3.5...5.0 %) in the raw material for the extruded protein-fat system was determined. The use of refined palm olein as an oil product resistant to oxidative deterioration, which should be added to raw components in order to correct the technological properties of the finished product, is substantiated.

The developed protein-fat system of reasonable composition has an advantage over a commercial similar product in terms of crude protein content (29.0 % vs. 8.2 %), porosity (130.0 % vs. 105.0 %) and cost ($ 916/t vs. $ 2,798/t). The obtained data are explained by the fact that a complex of components was used, some of which are production waste, with reasonable moisture and lipid content, which improved the technological characteristics of the extrudate. An applied aspect of using this scientific result is the possibility of rationalizing the extrusion process of oilseed meal to achieve the desired texture, porosity and stability of the lipid component of the product

Keywords: extrusion, protein-fat system, meal, corn grits, moisture content, lipid content, porosity

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1. Introduction

Almost all industries deal with the issues of environmental safety on the part of production: heavy industry [1], industrial agriculture, food, cosmetic, pharmaceutical and other industries [2, 3]. The priority task of food production, in particular the oil and fat industry, remains the processing and disposal of waste [4]. In addition, there is a need for constant monitoring of measures to improve food safety [5], determine their impact on the environment [6, 7] and human health [8]. It should be noted that the processing potential and volumes of oil raw materials are growing every year, and, as a result, the amount of waste is increasing. The task of reducing production waste can be solved by re-equipping modern production facilities and introducing low-waste or zero-waste technologies [9, 10]. According to statistics, production waste now accounts for 20–30 % of raw materials [11]. Currently, a systematic approach to waste management is being implemented all over the world, and the volume of waste generation is being reduced by increasing the volume of its processing and reuse [12].

Oil-producing enterprises produce an average of more than 400,000 tons of by-products per year [12]. The largest share of this volume of production by-products is made up of valuable protein-containing products (meal and cake) [13]. Cake is the seed mass that remains after pressing the oil raw material, and meal is the defatted seed mass formed by the extraction of vegetable oil from seeds. These by-products have a multi-component composition, which can vary significantly as a result of extraction of vegetable oils by various methods [14], as well as depending on the operating mode of the enterprise. Existing physico-chemical technologies for processing fatty by-products require rather strict conditions, significant capital costs and are ineffective. In addition, the demand for by-product processing products is not high enough [15]. Processing oil seed meal and cake for food purposes is an environmentally, economically and socially beneficial process. These by-products have a fairly low cost, they are a source of protein (the limiting amino acids are lysine and methionine), as well as unsaturated triglycerides, dietary fiber and a number of vitamins (in particular, vitamins of group *B* and *E*) [11]. The specified production should provide a sufficient amount of protein sources for food production.

A modern method of processing meal and cake into food products can be extrusion technologies, where raw materials are subjected to short-term high-temperature treatment under pressure. The effect of extrusion on the physical and chemical properties of the raw material is primarily determined by its initial composition and processing modes. The main effects of extrusion include [16]:

– destruction of the native structure of raw materials;
– gelatinization and partial dextrinization of starch;
– protein denaturation;
– sterilization of raw materials.

The extrusion method used in food production has a number of advantages [11]:

– inactivation of anti-alimentary factors;
– reduction of enzymatic oxidation of lipids;
– increase in the solubility of non-starch polysaccharides;
– the possibility of using various raw materials and additives (proteins, dietary fiber, vitamins, etc.) to increase the nutritional value;
– flexibility and continuity of the technological process;
– low production cost.

Extruded protein-fat systems are products or ingredients obtained by extruding a combination of protein- and lipid-containing raw materials. They can be used as components of various food products and are an alternative to foods containing meat as a source of protein [17]. Some types of meal, in particular soybean and sunflower, are quite widely processed into extrudates, which are used as food products and animal feed [11]. But there are a number of oilseed meals, in particular rapeseed and hemp, whose technological properties during extrusion have not been sufficiently studied. The nutritional value of these by-products is quite high due to the high content of proteins, dietary fiber, and vitamins [18, 19].

It is advisable to expand the range of raw components in the technology of extruded protein-fat systems such as crispbread, snacks, breakfast cereals, animal feed, etc. using meal of various oil crops. As mentioned above, the specified by-products of oil-producing enterprises have a high nutritional potential compared to grain raw materials (oats, corn, wheat), which is a traditional raw material component of extruded systems. The use of meal of oil crops, in particular soybean, rapeseed, hemp, which are promising in terms of nutritional value, will expand the range of extruded products. In addition, the identification of the dependences of the technological properties of extruded protein-fat systems on the moisture and lipid content in raw components contributes to the rationalization of production, improvement of product quality, and development of new protein-fat extruded systems. The implementation of the results of studying the influence of the extrusion parameters of the specified raw materials in the technological process of oilseed meal processing is necessary, as this will expand the range of products of food processing industries and contribute to increasing their market opportunities.

2. Literature review and problem statement

The study [11] considers ways to solve the problem of processing waste from the oil and fat industry, namely sunflower and soybean meal. The proportion of raw ingredients of the extruded system was determined: sunflower meal – 0.40 wt %; soybean meal – 0.25 wt %; oatmeal – 0.35 wt %. The development allows adjusting the porosity of finished products depending on the ratio of components in order to change the characteristics of the product according to consumer requirements. The disadvantage of the work is the uncertainty of the influence of moisture and lipid content in the raw material on the specified technological characteristics of the extrudate. An option to overcome the relevant difficulties can be to vary the moisture and lipid content in model samples of the mixture of raw components with determining the porosity of the corresponding extrudates.

In [20–23], the technology of extrudates from plant raw materials were developed, in particular rice extrudate with microencapsulated anthocyanins [20], extrudate based on mixtures of corn grits and buckwheat flour [21], soybean meal extrudate [22] and canola cake extrudate [23]. In these works, the researchers limited themselves to data on the influence of the moisture content of raw materials on the technological parameters of finished products and did not take into account the content of lipids in raw materials and its potential impact on the technological parameters of finished extrudates.

In the work [24], describing the rationalization of extrusion conditions for obtaining food granules (using corn, defatted soybean flour, sesame seeds, banana pulp), on the contrary, there is no information on the moisture content of raw materials. The authors of the study only indirectly record the moisture content of raw components due to variations in the content of banana pulp in the extrusion mixture.

Thus, as a result of research, the combined effect of lipid and moisture content on the extrudate expansion coefficient is proved. As for the density of the extrudate from the specified raw material, it is affected only by the moisture content (that is, the content of banana pulp).

The studies [25, 26] describe the influence of moisture and protein content on the technological properties of extrudates of protein-fat systems from pea and oat groats [25] and protein systems from hemp seeds and oat fiber [26]. The authors did not take into account the fat content, which is quite high in the specified raw materials (for example, in pea groats it is usually 1...2 %, in oat groats – 5...7 %, in oat fiber – 6...8 %). In addition, the authors examined the moisture content of raw materials, which is close to critical, and found that an increase in moisture content leads to a decrease in product density, a change in texture, and a deterioration in appearance [25]. With an increase in moisture content, it was found that the hardness and cutting strength indices decreased [26].

The authors of the work [27] analyzed the technological and nutritional properties of cotton flour extrudates without gossypol with the addition of a large amount of fish oil in extruded shrimp feed as an alternative to feed based on fish meal to reduce feeding costs. As a result of the research, the rational content of fish oil in cotton flour, as well as the rational moisture content to obtain extrudates with the necessary expansion coefficient, were substantiated.

Using the example of rice bran, the authors of the work [28] found that the content of proteins, lipids and moisture of the raw material affects the process of extrusion of the raw material. In particular, an increase in moisture content contributes to an increase in the yield strength of the extrudate, its better formation and, accordingly, a more even distribution of pressure inside the extruder. It is proved that a rational moisture content intensifies heat transfer during the extrusion process, which is necessary during the extrusion of thermoplastic materials. It is shown that excess moisture leads to such disadvantages as destruction of the extrudate structure and reduction of shelf life. In turn, the content of lipids in extrusion raw materials affects the texture and structural features of the extruded product. Rational fat content contributes to the formation of a porous structure of extruded systems, improves their plasticity. Issues related to the study of extrusion processes of other raw components, in particular oilseed meal, remain unsolved.

The results of analytical studies show that the content of moisture and lipids in the raw material significantly affects the extrusion process. If the raw material has a low moisture and lipid content, it can be stiff, which will make extrusion difficult. The high content of moisture and lipids also negatively affects the technological parameters of extrudates, in particular, their moisture content and porosity. It should be noted that during the extrusion of various raw materials, the rational level of moisture and lipids may differ depending on the properties of the raw materials, the target characteristics of the product, and extrusion parameters.

There is a certain lack of data on the effects of the combined effect of moisture and lipid content in the raw components of extruded protein-fat systems, in particular in the meal of such oil crops as soybean, rapeseed and hemp, on the technological parameters of finished products. In view of this, it is appropriate to study the influence of moisture and lipid content in the meal of certain oil crops and starch-containing raw materials on the technological properties of the extruded protein-fat system, in particular porosity and moisture content. This will make it possible to rationalize the composition and improve the texture of innovative extruded products based on the specified raw materials.

3. The aim and objectives of the study

The aim of the study is to identify the influence of moisture and lipid content on the technological properties of the extruded protein-fat system based on oilseed meals and grain raw materials. This will make it possible to determine the rational composition of the raw materials of the extruded protein-fat system to improve such technological indicators of the finished product as porosity and moisture content.

To achieve the aim, the following objectives were accomplished:

– to investigate the chemical composition of raw materials for the extruded protein-fat system;

– to investigate the combined effect of moisture and lipid content in model samples of raw materials on the porosity and moisture content of the extruded protein-fat system;

– to justify the type of refined oil as a raw component of the extruded protein-fat system resistant to oxidative deterioration;

– to compare the chemical composition, technological and economic indicators of the extruded protein-fat system with the existing similar product.

4. Research materials and methods

4. 1. Research object and hypothesis

The object of the research is technological indicators, in particular, the porosity and moisture content of the extruded protein-fat system, depending on the moisture and lipid content in the raw components. The main hypothesis of the study is the possibility of improving the porosity and moisture content of the finished extrudate using raw materials with a rational content of moisture and lipids.

The following assumptions were made in the study:

– the lipid component of any fatty acid composition equally affects the moisture content and porosity of the finished product due to the fact that it has similar properties under extrusion conditions;

– moisture in a bound and free state in the composition of raw materials equally affects the moisture content and porosity of the finished product due to the fact that it has similar properties under extrusion conditions.

The following simplification is adopted in the study.

Raw components for the extruded protein-fat system (soybean, rapeseed and hemp meal, corn grits) have the same content of fat, protein, and moisture as the raw material samples of the batches studied in the work. This ensures the repeatability of the determined dependencies during the production of the extruded protein-fat system with samples of other production batches.

4. 2. Research materials used in the experiment

The following materials were used during the research:

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

– crushed rapeseed meal (produced in Ukraine), according to CAS 8002-13-9;

– crushed hemp meal (produced in Ukraine), according to CAS 9000-70-8;

– crushed corn grits (produced in Ukraine), according to CAS 68525-86-0;

– refined sunflower oil (produced in Ukraine), according to CAS 8001-21-6;

– refined corn oil (produced in Ukraine), according to CAS 8001-30-7;

– refined palm olein (produced in Malaysia), according to CAS 93334-39-5.

In order to study the effect of the moisture and lipid content in the raw material on the porosity and moisture content of the extruded protein-fat system, a number of model samples of a mixture of raw components containing different amounts of lipids and moisture were developed. The moisture content in the initial mixture of raw components was changed by adding distilled water, the lipid content by adding refined sunflower oil. The duration of moistening, i.e. exposure of moistened and oil-enriched raw materials after homogenization, was 10 minutes.

4. 3. Methodology of raw material extrusion

Extrusion of raw materials was carried out on a PE-20 press extruder designed for obtaining swollen extruded products. The PE-20 press extruder has a replaceable screw with a nozzle that performs the function of a compression valve. The screw is driven by a V-belt transmission from an asynchronous electric motor. The screw speed is regulated by changing the pulleys of the V-belt transmission. The raw material for extrusion is fed into the feed hopper, which directs the material to the screw body. The angular velocity of the screw is measured using a tachometer. The process temperature is controlled in the area of the extruder forming head by a mini-multimeter. The temperature of the raw material in the pre-matrix zone does not exceed 135 °C. The screw speed is 250 revolutions per minute.

4. 4. Methods of determining the composition of raw materials and extruded products

In samples of raw materials and extruded products, the following are determined:

– the mass fraction of moisture and volatile substances – by the gravimetric method according to DSTU 7621;

– the mass fraction of protein – by the Kjeldahl method according to DSTU 7169;

– the mass fraction of lipids and fiber – by near-infrared spectroscopy according to DSTU 7491.

4. 6. Method for determining the porosity of extruded products

Porosity was determined by coating samples of extruded material with waterproof varnish. After drying, the samples were placed in a measuring container filled with water. The mass of water displaced from the cylinder by the processed extrudate was taken into account to determine the volume of the extrudate sample with pores. The extrudate sample was subjected to pressing and its volume was determined. The porosity of the extruded products was determined by the formula [11]:

$$P=(1-V_p/V_w)\cdot 100, (\%),$$

where V_p is the volume of the extrudate with pores, mm^3;

V_w is the volume of the extrudate after pressing the sample, mm^3.

4. 7. Method for determining the induction period of the lipid component of the extruded product

The induction period of the lipid component of the extruded product was carried out by the accelerated "reactive oxygen" method according to DSTU ISO 6886. The method consists in keeping the samples of the material under investigation at a constant elevated temperature (85±2 °C) and stirring and periodic determination of the peroxide value (*PV*) of the lipid component extracted from the samples. The peroxide number of lipids characterizes the degree of accumulation of primary oxidation products. The obtained values are presented as a graphical dependence of the *PV* value of the lipid component of the samples on the oxidation time. The induction period is defined graphically as a period of time after which a significant increase in *PV* occurred, that is, the concentration of primary oxidation products (peroxides and hydroperoxides).

4. 8. Research planning and statistical processing of results

To determine the dependence of the porosity and moisture content of the extruded protein-fat system on the moisture and lipid content in the raw material, the multifactor regression method with the construction of response surfaces was chosen. The method of full factorial experiment was used to build the model. For experiment planning and data processing, mathematical methods were applied using the Stat Soft Statistica v 6.0 software package (USA). The statistical model of dependence is determined by approximating the experimental data by constructing a trend line. The study was carried out three times.

The significance check of the coefficients of the equation of approximation dependences (2) and (3) of the porosity and moisture content of the extruded protein-fat system on the moisture and lipid content in the raw material was determined using the least squares method.

The quality of the equation of approximation dependencies (2) and (3) and the completeness of the effect of the selected factors (moisture and lipid content in the raw material) on the porosity and moisture content of the extruded protein-fat system were evaluated using the coefficients of determination R^2. The obtained values R^2=0.953 for dependence (2) and R^2=0.961 for dependence (3) allow us to draw a conclusion about the high influence of variations in moisture and lipid content of raw materials on variations in porosity and moisture content of the extruded product. The significance of the equation of approximation dependencies (2) and (3) is determined by calculating the Fisher test (F), based on the assumption (null hypothesis) that the equation is statistically insignificant. The calculated values of the Fisher test were:

– for approximation dependence (2): $F(2, 12)$=21.854,

– for approximation dependence (3): $F(2, 12)$=24.182.

The calculated values of the Fisher test are greater than its critical table value $F_{tab}(2, 12)$=3.88 at the significance level p=0.05. This result allows us to reject the null hypothesis and with a probability of 95 % recognize the value of the coefficients of determination R^2=0.953 for dependence (2) and R^2=0.961 for dependence (3) as significant, and the equations of approximation dependences (2) and (3) as significant.

4. 9. Method of analyzing the economic feasibility of using the proposed raw components

The economic effect ($E_{c.r.}$) is a decrease in the cost of production, provided that the use of components of extruded protein-fat systems in production is compared with a commercial analog and is calculated by the formula (1):

$$E_e=\sum_{i=1}^{n}P_i\cdot C_i-\sum_{j=1}^{m}P_j\cdot C_j, \qquad (1)$$

where P_i, P_j – the cost of the components of extruded protein-fat systems in the composition of the commercial analog and those offered, respectively, \$/kg; C_i, C_j – the content of the components of extruded protein-fat systems in the composition of the commercial analog and the proposed ones, respectively, kg/t.

5. Results of studies of the influence of the moisture and fat content of raw materials on the technological properties of the extruded protein-fat system

5. 1. Study of the chemical composition of raw materials for the extruded protein-fat system

As raw materials for the extruded protein-fat system, by-products of oil and fat production were chosen – crushed soybean, rapeseed and hemp meal, as well as corn grits. The content of lipids, moisture and volatile substances, crude protein and fiber of samples of raw materials for the extruded protein-fat system was studied (Table 1).

The research results show that the raw material samples for the extruded protein-fat system meet the requirements of the relevant regulatory documentation. The only difference is the moisture content of oilseed meal.

Based on the results of research on the rational ratio of protein- and starch-containing raw materials described in [11], a mixture of raw components with the following composition was extruded:

– soybean meal – 25 %;
– rapeseed meal – 25 %;
– hemp meal – 25 %;
– corn grits – 25 %.

As a result, an extruded product with the following chemical composition was obtained:

– lipid content – 1.32 %;
– content of moisture and volatile substances – 7.20 %;
– crude protein content – 29.90 %;
– fiber content – 14.40 %.

The composition indicators show that as a result of extrusion under the specified conditions (clause 4.3), the following decreased in the resulting product: the content of moisture and volatile substances (by 20.0 %); lipid content (by 4.3 %); crude protein content (by 1.6 %).

The porosity of the obtained extruded product is 68 %.

It is of interest to study the influence of moisture and lipid content in model samples of raw materials on the composition and technological parameters of the extruded protein-fat system (porosity and moisture content).

5. 2. Study of the influence of moisture and lipid content in model samples of raw materials on the porosity and moisture content of the extruded protein-fat system

The influence of the content of moisture (c_w) and lipids (c_f) in the raw material (item 5.1) in the ratio of 1:1:1:1 on the porosity (P (c_w, c_f)) and moisture (M (c_w, c_f)) of the extruded product was determined. The moisture content in the raw materials was varied in the range of 9.0...13.5 % with a step of 1.5 %. The content of lipids in the raw materials was varied in the range of 2.0...6.0 % with a step of 2.0 %.

The obtained values of the porosity of the extruded protein-fat system were within 68...135 %; the moisture content of the extruded protein-fat system – within 7.2...12.7 %. The surfaces of the obtained dependencies are presented in Fig. 1, 2.

Approximation dependences of the technological parameters of the extruded protein-fat system are presented by equations (2) and (3), namely:

– porosity (P (c_w, c_f));
– moisture content (M (c_w, c_f)) on the factors:
– moisture content (c_w) in raw materials;
– lipid content (c_f) in the raw material:

$$P(c_w, c_f)=-702.3333+135.2778\cdot c_w+13.625\cdot c_f-5.8148\cdot c_w^2+0.4167\cdot c_w\cdot c_f-1.9063\cdot c_f^2; \qquad (2)$$

$$M(c_w, c_f)=7.9917-0.5411\cdot c_w+0.1125\cdot c_f+0.0407\cdot c_w^2+0.0233\cdot c_w\cdot c_f. \qquad (3)$$

It should be noted that the given approximation dependencies describe the real process adequately in the ranges of moisture content in raw materials 9.0...13.5 % and lipid content in raw materials – 2.0...6.0 %.

Based on the obtained results of experiments and their statistical processing, the moisture and lipid content in the raw materials selected for extrusion was adjusted. The rational range of the studied factors for obtaining an extruded protein-fat system of satisfactory porosity and moisture content is outlined, namely:

– moisture content in raw materials – 10.5...12.5 %;
– lipid content in raw materials – 3.5...5.0 %, for which the technological indicators of products in the extrusion process increased, namely:
– porosity – 112...135 %;
– moisture content – 8.0...9.2 %.

Table 1

Chemical composition of samples of raw materials for the extruded protein-fat system

Type of raw material	Content, %							
	lipids		moisture and volatile substances		crude protein		fiber	
	Experiment	Norm	Experiment	Norm	Experiment	Norm	Experiment	Norm
Soybean meal	1.40±0.05	no more than 1.5	7.20±0.31	8.5...10.0	41.50±1.66	not less than 40.0	4.90±0.20	no more than 5.0
Rapeseed meal	1.80±0.07	no more than 3.0	7.80±0.35	8.0...12.0	38.00±1.52	not less than 37.0	14.20±0.57	no more than 16.0
Hemp meal	1.20±0.04	no more than 1.5	6.50±0.21	7.5...9.0	33.50±1.34	not less than 32.0	32.00±1.28	no more than 35.0
Corn grits	1.10±0.04	not normalized	14.0±0.50	no more than 14.0	8.50±0.34	not normalized	5.00±0.20	not normalized

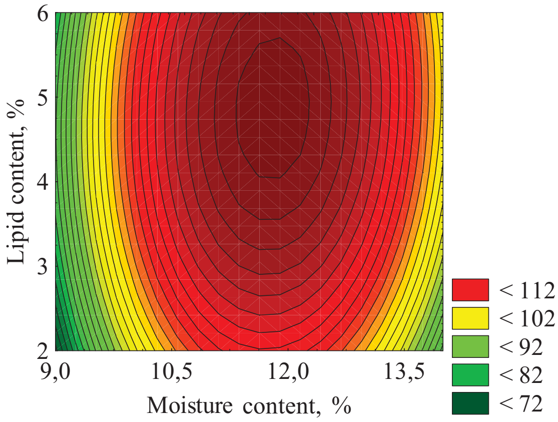

Fig. 1. Dependence of the porosity ($P(c_w, c_f)$) of the extruded protein-fat system on the moisture (c_w) and lipid (c_f) content in the raw material

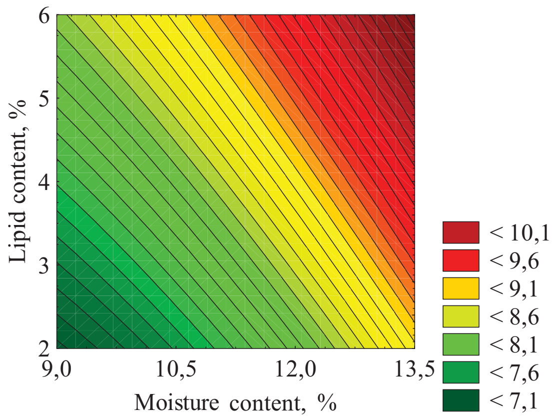

Fig. 2. Dependence of the moisture content ($M(c_w, c_f)$) of the extruded protein-fat system on the moisture (c_w) and lipid (c_f) content in the raw material

It is worth noting that an increase in the moisture content of the specified raw material by more than 10.0...12.0 % leads to an increase in the moisture content of the obtained extruded product. This, in turn, requires additional drying, which is impractical from an economic (product cost increases) and technological (product porosity decreases) point of view. When the lipid content in the raw material increases to more than 5.5 %, the porosity of the finished product also decreases, and unsatisfactory organoleptic characteristics (specific aroma and taste) appear. It is possible to predict the intensification of the oxidation processes of the lipid component in such products, which will negatively affect the quality indicators of the finished product.

5. 3. Justification of the type of refined oil as a raw component of the extruded protein-fat system

A study of the period of accelerated oxidation of the lipid component of the extruded protein-fat system of the proposed composition depending on the type of refined oil added to the raw material was carried out. Refined sunflower and corn oils, as well as palm olein, were used in the experiments. The periods of induction of the lipid component of the extrudate samples were determined in comparison with the same indicator of the existing similar product. As an analog, "Molodist" extruded multi-grain cereal flakes (manufacturer Ukraine, declared composition: an extruded mixture of wheat fiber, buckwheat groats, amaranth meal, flax meal) were chosen, which was chosen as a comparison sample [29]. This product was chosen as a comparison sample due to similar components (starch-, protein-, and lipid-containing components), as well as fat content at the level of 4.5...5.0 %. The change in the peroxide value of the lipid fraction of the model samples and the comparison sample in the process of accelerated oxidation is shown in Fig. 3.

The periods of induction of accelerated oxidation of the lipid fraction of samples of extruded protein-fat systems depending on the addition to the raw materials:

– refined sunflower oil – 170 min.;
– refined corn oil – 225 min.;
– refined palm olein – 330 min.

The period of induction of accelerated oxidation of the lipid fraction of the comparison sample was 110 min. Thus, it is reasonable to use refined palm olein as a source of lipids in the extruded protein-fat system of the proposed composition.

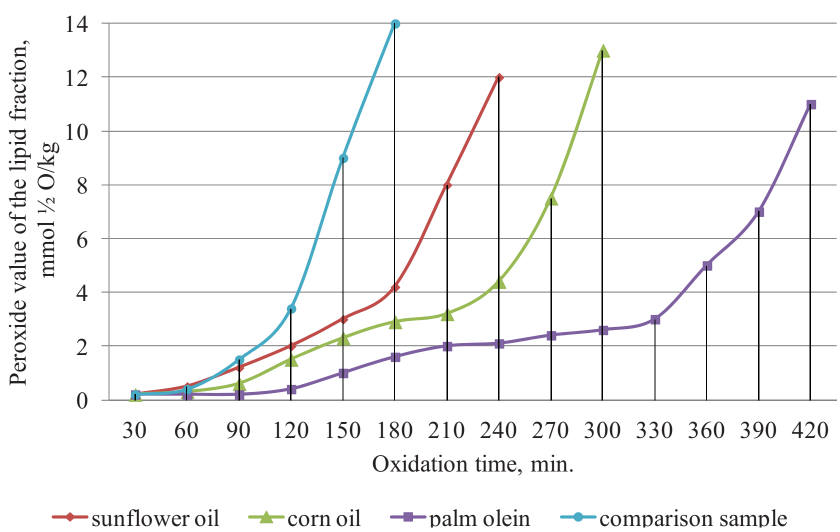

Fig. 3. Change in the peroxide value of the lipid fraction of samples of extruded protein-fat systems depending on the type of refined vegetable oil added to the mixture of raw materials before extrusion compared to the existing analog

5. 4. Comparison of the indicators of the extruded protein-fat system with a similar product

Based on the results of the research (Fig. 1, 2) and dependencies (2) and (3), an experimental sample of the extruded protein-fat system was obtained. The raw material is a mixture of soybean, rapeseed, hemp and corn grits in a 1:1:1:1 ratio with the addition of refined palm olein in an amount of 3.2 %. The moisture content of this extrusion mixture was increased by means of moistening, homogenization and exposure (moistening – 10 minutes) to 11.5 %.

The composition of the studied sample of the extruded protein-fat system compared to the existing analog is given in Table 2 (the estimated moisture content of the extruded protein-fat system of the proposed composition was 8.8 %).

Table 2

Characteristics of the studied samples of extruded products

Characteristic	Samples of extruded protein-fat systems	
	Developed	Existing similar product (comparison sample)
Lipid content, %	4.40±0.16	4.60±0.18
Content of moisture and volatile substances, %	8.50±0.34	9.10±3.70
Crude protein content, %	29.00±1.16	8.20±0.33
Fiber content, %	14.20±0.57	56.10±2.24
Porosity, %	130.0±5.2 %	105.0±4.2 %

The sample of the extruded protein-fat system of the proposed composition almost does not differ in lipid content from the sample of the existing similar product (4.40±0.16 % vs. 4.60±0.18 %, respectively). The same pattern applies to the content of moisture and volatile substances (8.50±0.34 % vs. 9.10±3.70 %, respectively). The content of crude protein in the extruded protein-fat system of the proposed composition exceeds that in the comparison sample by 3.5 times (29.00±1.16 % vs. 8.20±0.33 %, respectively). The fiber content in the extruded protein-fat system of the proposed composition, on the contrary, is 3.9 times less than that in the comparison sample (14.20±0.57 % vs. 56.10±2.24 %, respectively).

The porosity of the extruded protein-fat system of the proposed composition exceeds that of the existing similar product by 24 % (130.0±5.2 % (calculated value – 128.0 %) and 105.0±4.2 %, respectively).

The results of the analysis of the economic feasibility of using the proposed raw components in the technology of the extruded protein-fat system are shown in Table 3.

Table 3

Analysis of the economic feasibility of using the proposed raw components in the technology of the extruded protein-fat system

Raw component	Cost, $/kg	Content in the product, kg/t	Product cost, $/ton
Extruded protein-fat system developed			
Soybean meal	0.63	242	916
Rapeseed meal	0,24	242	
Hemp meal	1.97	242	
Corn grits	0.42	242	
Refined palm olein	1.36	32	
Comparison product			
Wheat fiber	3.76	100	2 798
Buckwheat groats	1.71	400	
Amaranth meal	3.95	200	
Flax meal	4.74	200	

The calculations given in Table 3 prove the economic feasibility of production of the extruded protein-fat system using the selected raw components. The cost of such a product is 3 times lower than that of the comparison product – extruded multi-grain cereal flakes.

6. Discussion of the results of determining the influence of the raw material composition on the properties of the extruded protein-fat system

The obtained research results allow rationalizing the component composition and improving the texture of innovative extruded products based on soybean, rapeseed and hemp meal due to the combined effect of moisture and lipids on the technological parameters of the extrudate. The influence of moisture and fat content on the technological properties of the extruded protein-fat system based on the waste of oil and fat production and grain raw materials, namely crushed soybean, rapeseed and hemp meal, as well as corn grits, was revealed. The use of oilseed meal as a raw material for the extruded protein-fat system is justified due to its high nutritional value (Table 1) and relatively low cost (Table 3).

Meals of the selected oil crops contain a significant amount of crude protein (41.5%, 38.0 % and 33.5 %, respectively) and dietary fiber (4.9 %, 14.2 % and 32.0 %, respectively) (Table 1).

The content of moisture and volatile substances in the studied samples of raw materials (Table 1) is somewhat lower than the established norms. This can be explained by the relative freshness of samples recently obtained from production.

Based on the meal of the selected oilseeds and a common raw material for extruded products, corn grits, in a ratio of 1:1:1:1, an extruded protein-fat system was developed, in which the content of moisture and volatile substances, lipids and crude protein decreased compared to the original raw material.

Changes in the composition of products during extrusion can be explained by the flow of processes of thermal denaturation and thermal degradation of proteins under the influence of high pressure, as well as thermal oxidation of lipids. It is likely that chemical reactions also occur between proteins and other components of raw materials, in particular sugars and lipids [22, 24], which leads to a slight decrease in their content in the finished product.

The effect of moisture and lipid content in model samples of raw materials on the porosity (Fig. 1, equation (2)) and moisture content (Fig. 2, equation (3)) of the extruded protein-fat system was studied. This allows us to outline the range of the specified parameters that positively affect the efficiency of the extrusion process. The obtained research results can be explained primarily by the fact that a reasonable ratio of fat and water affects the thermorheological properties of the mixture of raw components during extrusion. This ratio provides proper consistency and yield strength of the raw material, reduces friction, ensures uniform heating during extrusion, which contributes to more efficient processing and forming of the extrudate. In addition, the specified water content provides conditions for steam to affect the extrudate, which increases the pressure in the extruder drum, contributing to the expansion and formation of the required pore size and degree of expansion of the extruded product.

The type of refined vegetable oil added to the raw components to improve porosity is substantiated, taking into account the oxidative stability of the lipid component of the extruded protein-fat system. The lipid component of the product based on refined palm olein showed the greatest resistance to oxidation compared to refined sunflower and corn oils (Fig. 3). This is explained by the specificity of the fatty acid composition of the oils, namely the high content of oleic fatty acid residues in the composition of triglycerides of palm olein, which is more resistant to oxidative damage compared to acyls of linoleic fatty acid, which prevails in the composition of triglycerides of sunflower and corn oils.

The chemical composition and technological parameters of the extruded protein-fat system of the developed composition are compared with the existing similar product, "Molodist" extruded multi-grain cereal flakes (manufacturer Ukraine) (Table 2). The increase in crude content protein and the decrease in fiber content in the new product are caused by the chemical composition of protein-containing raw components used (soybean, rapeseed and hemp meal). The closeness of the analyzed samples in terms of moisture, volatile substances and lipid content is explained by the purposeful regulation of these indicators (according to equations (2) and (3)). This is also the reason for the improved porosity of the new product compared to its counterpart.

The analysis of the economic feasibility of using the proposed raw components in the technology of the extruded protein-fat system (Table 3) proved the priority of using the selected raw components compared to the raw components of a similar commercial product. The lower cost of the developed product compared to its counterpart is due to the rather low price of the raw materials used, namely the meal of the selected oil crops – by-products of oil-producing enterprises.

The development differs from the results of the study [11], where a rational ratio of the basic components of extruded animal feed was determined without varying the moisture and lipid content. Also, the development differs from the works [27, 28], where the influence of the moisture and fat content of the raw material on the technological parameters of extruded products was investigated, because protein-containing by-products of the oil-producing industry in combination with grain raw materials were chosen as raw components. The extruded protein-fat system of the developed composition has a high crude protein content (Table 2), as well as high porosity due to the rational ratio of moisture and lipids in the raw material (Fig. 1). In addition, the lipid component of the developed product is stable to oxidative damage (Fig. 3). The specified technological properties, as well as economic characteristics (Table 3), are unconditional competitive advantages in the market of extruded products. This is due to the combination of meal from various types of oil plants (soybean, rapeseed, hemp), corn grits as a source of starch, as well as oxidation-stable oil raw materials – refined palm olein as raw components.

The results of the research, namely dependencies (2) and (3), allow us to substantiate the effective composition of by-products (meals) of oil and fat production for the technology of extruding plant raw materials for food production. The results of the work (Table 2, approximation dependencies (2) and (3)) can contribute to the wider use of unconventional raw materials, in particular oil and fat production waste in the technology of extruded protein-fat systems. In addition, this will allow you to carry out technological operations to rationalize production such as moistening and adding an oil component.

The limitation of the obtained research results is that the raw materials for the production of extruded protein-fat systems with a certain chemical composition were used in the experimental studies (Table 1). Therefore, in the case of using raw components of a different composition, it is necessary to adjust the total content of moisture and lipids in the original mixture.

The disadvantage of the study is the lack of research results on the effect of changing the ratio of raw materials (crushed soybean meal, rapeseed and hemp meal, corn grits) on the technological indicators of the extruded protein-fat system.

It is worth noting promising areas of work regarding the influence of moisture and fat content in raw materials on the technological properties of the extruded protein-fat system. This is primarily a study of the physico-chemical interactions between proteins, fats and flavorings that must be added during the extrusion process.

7. Conclusions

1. The chemical composition (content of lipids, moisture, crude protein, and fiber) of protein-containing (soybean, rapeseed, and hemp meal) and starch-containing (corn grits) raw materials for the extruded protein-fat system was studied. Samples of raw materials meet the requirements established in the relevant regulatory documentation – CAS 68308-36-1, CAS 8002-13-9, CAS 9000-70-8, CAS 68525-86-0. The lower moisture content compared to the established norms can be explained by the relative freshness of the samples that were recently received from production.

2. The effect of moisture and lipid content in model samples of raw materials on the porosity and moisture content of the extruded protein-fat system was investigated. A rational ratio of moisture content (10.5...12.5 %) and lipids (3.5...5.0 %) in raw materials for the extrudate is determined.

3. The use of refined palm olein as a raw material component of the extruded protein-fat system resistant to oxidative deterioration is justified. The induction period of accelerated oxidation of the lipid fraction of the extrudate with refined palm olein was 330 min. compared to the use of refined sunflower (170 min.) and corn (225 min.) oils.

4. The physico-chemical, technological and economic indicators of the extruded protein-fat system of the developed composition were compared with the same indicators of the existing similar product (extruded multi-grain cereal flakes). The indicators of the composition of the developed extrudate correspond to those of the comparison product in terms of lipid content (4.4 % vs. 4.6 %), moisture and volatile substances (8.5 % vs. 9.1 %). The indicators of the

developed extrudate exceed those of the comparison product in terms of crude protein content (29.0 % vs. 8.2 %) and porosity (130 % vs. 105 %). The fiber content in the developed product is lower than in the comparison product (14.2 % vs. 56.1 %). The cost of the developed product is 3 times lower than that of the comparison product.

Conflict of interest

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

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Data availability

The manuscript has no associated data.

References

1. Sokolov, V. M., Gorbenko, V. V., Vinnik, I. A., Mekhed, O. M. (2006). Processing the Ni- And Cr-bearing oxidized scarfing granulates with liquid cast iron. Extraction and Processing Division: Sohn International Symposium, 1, 453–462.
2. Danchenko, Y., Andronov, V., Barabash, E., Obigenko, T., Rybka, E., Meleshchenko, R., Romin, A. (2017). Research of the intramolecular interactions and structure in epoxyamine composites with dispersed oxides. Eastern-European Journal of Enterprise Technologies, 6 (12 (90)), 4–12. doi: https://doi.org/10.15587/1729-4061.2017.118565
3. Vambol, S., Bogdanov, I., Vambol, V., Suchikova, Y., Lopatina, H., Tsybuliak, N. (2017). Research into effect of electrochemical etching conditions on the morphology of porous gallium arsenide. Eastern-European Journal of Enterprise Technologies, 6 (5 (90)), 22–31. doi: https://doi.org/10.15587/1729-4061.2017.118725
4. Vambol, S., Vambol, V., Kondratenko, O., Koloskov, V., Suchikova, Y. (2018). Substantiation of expedience of application of high-temperature utilization of used tires for liquefied methane production. Journal of Achievements in Materials and Manufacturing Engineering, 87 (2), 77–84. doi: https://doi.org/10.5604/01.3001.0012.2830
5. Kovaliova, O., Tchoursinov, Y., Kalyna, V., Koshulko, V., Kunitsia, E., Chernukha, A. et al. (2020). Identification of patterns in the production of a biologically-active component for food products. Eastern-European Journal of Enterprise Technologies, 2 (11 (104)), 61–68. doi: https://doi.org/10.15587/1729-4061.2020.200026
6. Loboichenko, V. M., Vasyukov, A. E., Tishakova, T. S. (2017). Investigations of Mineralization of Water Bodies on the Example of River Waters of Ukraine. Asian Journal of Water, Environment and Pollution, 14 (4), 37–41. doi: https://doi.org/10.3233/ajw-170035
7. Sadkovyi, V., Pospelov, B., Andronov, V., Rybka, E., Krainiukov, O., Rud, A. et al. (2020). Construction of a method for detecting arbitrary hazard pollutants in the atmospheric air based on the structural function of the current pollutant concentrations. Eastern-European Journal of Enterprise Technologies, 6 (10 (108)), 14–22. doi: https://doi.org/10.15587/1729-4061.2020.218714
8. Pospelov, B., Andronov, V., Rybka, E., Krainiukov, O., Maksymenko, N., Meleshchenko, R. et al. (2020). Mathematical model of determining a risk to the human health along with the detection of hazardous states of urban atmosphere pollution based on measuring the current concentrations of pollutants. Eastern-European Journal of Enterprise Technologies, 4 (10 (106)), 37–44. doi: https://doi.org/10.15587/1729-4061.2020.210059
9. Vambol, S., Vambol, V., Sychikova, Y., Deyneko, N. (2017). Analysis of the ways to provide ecological safety for the products of nanotechnologies throughout their life cycle. Eastern-European Journal of Enterprise Technologies, 1 (10 (85)), 27–36. doi: https://doi.org/10.15587/1729-4061.2017.85847
10. Vambol, S., Bogdanov, I., Vambol, V., Suchikova, Y., Kondratenko, O., Hurenko, O., Onishchenko, S. (2017). Research into regularities of pore formation on the surface of semiconductors. Eastern-European Journal of Enterprise Technologies, 3 (5 (87)), 37–44. doi: https://doi.org/10.15587/1729-4061.2017.104039
11. Petik, I., Litvinenko, O., Kalyna, V., Ilinska, O., Raiko, V., Filenko, O. et al. (2023). Development of extruded animal feed based on fat and oil industry waste. Eastern-European Journal of Enterprise Technologies, 2 (11 (122)), 112–120. doi: https://doi.org/10.15587/1729-4061.2023.275509
12. Wallace, T., Gibbons, D., O'Dwyer, M., Curran, T. P. (2017). International evolution of fat, oil and grease (FOG) waste management – A review. Journal of Environmental Management, 187, 424–435. doi: https://doi.org/10.1016/j.jenvman.2016.11.003
13. Tsykhanovska, I., Evlash, V., Alexandrov, A., Lazarieva, T., Svidlo, K., Gontar, T. et al. (2018). Substantiation of the mechanism of interaction between biopolymers of rye¬and¬wheat flour and the nanoparticles of the magnetofood food additive in order to improve moisture¬retaining capacity of dough. Eastern-European Journal of Enterprise Technologies, 2 (11 (92)), 70–80. doi: https://doi.org/10.15587/1729-4061.2018.126358
14. Danchenko, Y., Andronov, V., Kariev, A., Lebedev, V., Rybka, E., Meleshchenko, R., Yavorska, D. (2017). Research into surface properties of disperse fillers based on plant raw materials. Eastern-European Journal of Enterprise Technologies, 5 (12 (89)), 20–26. doi: https://doi.org/10.15587/1729-4061.2017.111350
15. Petik, I., Belinska, A., Kunitsia, E., Bochkarev, S., Ovsiannikova, T., Kalyna, V. et al. (2021). Processing of ethanol-containing waste of oil neutralization in the technology of hand cleaning paste. Eastern-European Journal of Enterprise Technologies, 1 (10 (109)), 23–29. doi: https://doi.org/10.15587/1729-4061.2021.225233

16. Singh, S., Gamlath, S., Wakeling, L. (2007). Nutritional aspects of food extrusion: a review. International Journal of Food Science & Technology, 42 (8), 916–929. doi: https://doi.org/10.1111/j.1365-2621.2006.01309.x
17. Papchenko, V., Matveeva, T., Bochkarev, S., Belinska, A., Kunitsia, E., Chernukha, A. et al. (2020). Development of amino acid balanced food systems based on wheat flour and oilseed meal. Eastern-European Journal of Enterprise Technologies, 3 (11 (105)), 66–76. doi: https://doi.org/10.15587/1729-4061.2020.203664
18. Sentís-Moré, P., Ortega-Olivé, N., Mas-Capdevila, A., Romero-Fabregat, M.-P. (2022). Impact of centrifugation and vacuum filtration step on the yield and molecular weight distribution of protein hydrolysates from rapeseed and sunflower meals. LWT, 165, 113741. doi: https://doi.org/10.1016/j.lwt.2022.113741
19. Malomo, S. A., Aluko, R. E. (2015). Conversion of a low protein hemp seed meal into a functional protein concentrate through enzymatic digestion of fibre coupled with membrane ultrafiltration. Innovative Food Science & Emerging Technologies, 31, 151–159. doi: https://doi.org/10.1016/j.ifset.2015.08.004
20. Kamali Rousta, L., Bodbodak, S., Nejatian, M., Ghandehari Yazdi, A. P., Rafiee, Z., Xiao, J., Jafari, S. M. (2021). Use of encapsulation technology to enrich and fortify bakery, pasta, and cereal-based products. Trends in Food Science & Technology, 118, 688–710. doi: https://doi.org/10.1016/j.tifs.2021.10.029
21. Singh, J. P., Kaur, A., Singh, B., Singh, N., Singh, B. (2019). Physicochemical evaluation of corn extrudates containing varying buckwheat flour levels prepared at various extrusion temperatures. Journal of Food Science and Technology, 56 (4), 2205–2212. doi: https://doi.org/10.1007/s13197-019-03703-y
22. Mazaheri Tehrani, M., Ehtiati, A., Sharifi Azghandi, S. (2017). Application of genetic algorithm to optimize extrusion condition for soy-based meat analogue texturization. Journal of Food Science and Technology, 54 (5), 1119–1125. doi: https://doi.org/10.1007/s13197-017-2524-9
23. Zhang, B., Liu, G., Ying, D., Sanguansri, L., Augustin, M. A. (2017). Effect of extrusion conditions on the physico-chemical properties and in vitro protein digestibility of canola meal. Food Research International, 100, 658–664. doi: https://doi.org/10.1016/j.foodres.2017.07.060
24. Mridula, D., Sethi, S., Tushir, S., Bhadwal, S., Gupta, R. K., Nanda, S. K. (2017). Co-extrusion of food grains-banana pulp for nutritious snacks: optimization of process variables. Journal of Food Science and Technology, 54 (9), 2704–2716. doi: https://doi.org/10.1007/s13197-017-2707-4
25. Saldanha do Carmo, C., Varela, P., Poudroux, C., Dessev, T., Myhrer, K., Rieder, A. et al. (2019). The impact of extrusion parameters on physicochemical, nutritional and sensorial properties of expanded snacks from pea and oat fractions. LWT, 112, 108252. doi: https://doi.org/10.1016/j.lwt.2019.108252
26. Zahari, I., Purhagen, J. K., Rayner, M., Ahlström, C., Helstad, A., Landers, M. et al. (2023). Extrusion of high-moisture meat analogues from hempseed protein concentrate and oat fibre residue. Journal of Food Engineering, 354, 111567. doi: https://doi.org/10.1016/j.jfoodeng.2023.111567
27. Delgado, E., Valles-Rosales, D. J., Flores, N. C., Reyes-Jáquez, D. (2021). Evaluation of fish oil content and cottonseed meal with ultralow gossypol content on the functional properties of an extruded shrimp feed. Aquaculture Reports, 19, 100588. doi: https://doi.org/10.1016/j.aqrep.2021.100588
28. Rashid, M. T., Liu, K., Han, S., Jatoi, M. A., Sarpong, F. (2023). Optimization of Extrusion Treatments, Quality Assessments, and Kinetics Degradation of Enzyme Activities during Storage of Rice Bran. Foods, 12 (6), 1236. doi: https://doi.org/10.3390/foods12061236
29. Plastivtsi ekstrudovani multyzlakovi «Molodist». Available at: https://prom.ua/ua/p1521753798-hlopya-ekstrudirovannye-multizlakovye.html