The object of the study is the technological indicators of the emulsion protein-fat system developed on the basis of oilseeds and their processing products. The research problem is the need to stabilize the emulsion of the protein-fat system of plant origin. The solution to the problem of adjusting the technological indicators of emulsion protein-fat systems based on flax seeds and soybean meal is considered, in particular, the stability of the emulsion and resistance to oxidative damage. An emulsion protein-fat system with an increased content of ω-3 polyunsaturated fatty acids (ALA) based on a mixture of flax seeds and soybean meal is developed. The influence of the ratio of raw materials on the stability of the emulsion system is investigated. It was found that the rational ratio of flax seeds (40 %) and soybean meal (60 %) provides high resistance of the lipid component to oxidative damage, which is confirmed by the increase in the peroxide value by only 0.9 mmol ½O/kg after 30 days of storage. The effect of stabilizers – xanthan gum (0.5 %) and polyoxyethylene (20) sorbitan monolaurate (0.2 %) – on the stability of the emulsion protein-fat system during 30-day storage at a temperature of 4 °C was studied.

The emulsion system of the developed composition is characterized by a lower protein content compared to the reference sample (by 8 %), however, this disadvantage is compensated by the balance of the fatty acid composition, a significantly higher content of ω-3 PUFA (9.8 % vs. 0 %) and lipids (17.7 % vs. 1.1 %). Such characteristics significantly increase its nutritional value. The developed protein-fat system has significant potential for implementation in the food industry, contributing to the creation of new products with a high ALA content and expanding the range of emulsion products that meet modern standards of healthy nutrition

Keywords: emulsion protein-fat system, flax seeds, soybean meal, alpha-linolenic acid, technological indicators

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DEVELOPMENT OF THE EMULSION PROTEIN-FAT SYSTEM COMPOSITION

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1. Introduction

Secondary resources of plant raw materials are actively used in solving food, environmental and energy problems, as an additional source of substances of natural origin [1]. A significant amount of such secondary resources is formed in the process of processing oilseeds. The oil and fat industry, processing oilseeds, extracts the target component – vegeta-

ble oil – from it, and at the same time receives a large number of secondary products – cake and meal [2]. A valuable property of oilseeds and many meals is their high protein content, fairly low cost and the absence of toxic and anti-nutrients after appropriate processing [3].

The creation of mass consumption products of increased nutritional and biological value, as well as products of preventive and dietary purposes requires the expansion and improvement of the raw material base of the domestic industry. A promising direction for the development of the processing industry is the rational use of secondary protein-fat raw materials of plant and animal origin, expanding the range of protein-fat systems and products based on them. One of these directions is the production of emulsion protein-fat systems of increased nutritional and biological value [4].

Existing studies on the enrichment of food systems with essential substances to improve their quality involve a balanced amino acid composition of proteins, fatty acid composition of lipids, and both together. However, all these works usually involve the use of raw materials of animal origin – meat, meat products, casein, whey proteins, etc. [5]. Research on the development of scientific and practical foundations for the creation of plant food protein-fat systems characterized by a rational ratio of protein and lipid components is an urgent task. These emulsion systems should involve the use of fat mixtures of regulated composition, prepared on the basis of vegetable oils, as lipid components. Such systems are used in the production of new or improved traditional food products that are convenient to store for a long time [6]. It is known that proteins and lipids have an immunomodulatory effect and are the basis of all chemical processes occurring in the body. The technological properties of proteins and lipids are understood as a wide range of physicochemical characteristics that determine their behavior during processing into food products and subsequent storage. These properties are the basis for the formation of the structure, technological and consumer qualities of finished products [7]. Research in this area is of key importance for the development of protein and lipid processing technologies, in particular for the creation of new systems and improvement of the production of traditional food products. The technological properties of proteins include solubility, the degree of swelling in water, as well as in saline, alkaline and acidic environments. An important role is played by the compatibility of proteins with other components of food raw materials, their ability to form and stabilize dispersed systems (foams, emulsions, suspensions), gels, as well as to exhibit adhesive, rheological and organoleptic properties [5, 8]. In general, technological properties can be considered as a set of physicochemical characteristics of a protein-containing system that simulates real technological processes of processing raw materials to create food products. The requirements for these properties differ depending on the specifics of the process of processing proteins into certain food products, which makes it possible to justify the parameters of technological processes and optimize production [9]. Technological properties of proteins are closely related to their amino acid composition, structure and physicochemical properties. They determine the specifics of protein-protein interactions (gelation); protein-water (water-binding capacity, solubility); protein-lipids (fat-absorbing and fat-retaining capacity), as well as surface-active properties (formation and stabilization of foams and emulsions) [10]. Therefore, research aimed at substantiating the composition of the emulsion protein-fat system will provide an opportunity to expand the range of useful emulsion products based on valuable plant raw materials and secondary products of the oil and fat industry. The obtained scientific results are relevant for food production, in particular oil and fat production, since there is a need to expand the range and increase the nutritional value of emulsion protein-fat systems and increase their shelf life.

2. Literature review and problem statement

The paper [11] presents the results of research on the creation of a stable oil-based system as a cream substitute in ice cream. The use of an emulsion based on pomelo fiber and soy protein isolate as a cream substitute in ice cream was investigated. The results show that pomelo fiber in combination with soy protein isolate effectively stabilizes corn oil, forming an oil-in-water emulsion gel. Increasing the proportion of pomelo fiber increases the elastic modulus of the emulsion, reduces the average particle size and improves stability. Gel-like emulsion oil increases stability, reduces the stability index of the suspension for ice cream and improves the flow rate and melting resistance. Sensory evaluation of ice cream confirmed that the emulsion gel based on pomelo fiber and soy protein isolate is an effective and innovative fat substitute in the plant body. This gel provides a reduced calorie product and offers an innovative approach to replacing traditional fats in formulations. However, questions remain regarding the stability of such an emulsion system during storage and the possibility of using other protein sources to achieve a similar effect.

The above-mentioned research questions [11] were answered to some extent in [12], which investigated the effect of whey protein and corn oil on emulsion gels with a high internal phase to improve the texture of processed cheese. The gel strength, water retention capacity, rheological and heat-resistant properties of the gel, as well as the texture and melting properties of the cheese were characterized. It was shown that corn oil, when pre-emulsified with thermally denatured whey protein, forms a stable hexagonal structure at a higher oil content. Cheese made from such gels had a soft texture, and corn oil was more effective than milk fat in reducing cheese hardness. However, the question of the effect of alternative vegetable proteins on the formation of the emulsion system and the evaluation of their sensory properties in finished products remains unresolved. This issue is definitively addressed in the study [13], where the effect of lipids in different physical states on the gelation of *MP* was studied in order to improve the characteristics of the myofibrillar protein (*MP*) gel. It was shown that the addition of refined palm oil (*RPO*) increases the physicochemical parameters of the gel, improves the water-holding capacity and increases the thermal stability of the system. *MP-RPO* demonstrated the best thermal properties compared to *MP-CF* (chicken fat) and *MP-ST* (palm stearin). However, it is unclear how this method can be applied to stabilize protein-fat systems based on plant components, which limits their use in vegetarian or vegan products. This approach was used in the work [14], where emulsion gels were investigated for oil structuring, delivery of bioactive compounds and development of nutritious food products with reduced calorie content. It has been shown that the rheological, textural, and mechanical properties of emulsion hydrogels can be varied by adjusting the composition, oil concentration, gelation method, and gelation environment (pH, temperature, etc.). The question of optimizing the composition of complex

stabilizers for emulsion protein-fat systems based on plant raw materials remains unresolved.

In [15], the results of research on the development of emulsion gels "oil-in-water" based on hydrolysates of quinoa protein, alginate, and high-oleic sunflower oil, which evaluate antioxidant activity and viscoelastic properties, are presented. It was found that quinoa protein concentrate (*QPC*) and its hydrolysates (*QPH*) demonstrate high antioxidant activity and efficiency in reducing lipid oxidation. *QPH* was shown to have greater chelating activity and reducing capacity than *QPC*. However, the strengthening of emulsion gels based on *QPH* was less than that of *QPC*, which may limit the use of such systems in products with a long shelf life. However, issues related to the optimization of the composition of stabilizers to create stable emulsion protein-fat systems based on other plant proteins, such as soy, remain unresolved. In [16], the possibility of increasing the nutritional value of wheat flour by adding sunflower and soybean meal was analyzed. It was found that the addition of meal compositions improves the amino acid composition of products, but the issues related to the comprehensive development of emulsion systems with a high content of proteins and polyunsaturated fatty acids (PUFA) to create stable food systems remain unresolved.

Such studies were carried out in [17], where answers were given to a certain extent regarding the study of the use of soy protein isolates and polysaccharides as structure-forming agents for the creation of stable emulsions. It was shown that the formulation using soy protein isolate, alginates and starch ensures the creation of emulsions with a stable consistency and increased density. However, issues related to the optimization of the ratio of proteins and polysaccharides in systems based on flaxseed and secondary products of the oil industry remain unresolved. In addition, the study [18] considered the problem of creating a dressing stable to oxidation based on cold-pressed flaxseed, corn and sesame oils. The emulsion was stabilized by a complex based on soy protein. However, issues related to the selection of complex stabilizers for emulsion protein-fat systems remain unresolved. These questions were answered to some extent in the work [19], which investigated the creation of emulsion systems based on hemp oil. It was found that the addition of lecithin, soy protein and xanthan gum contributes to increasing the resistance of emulsions to oxidation. It would be advisable to conduct research related to the creation of an emulsion protein-fat system based on protein-containing plant raw materials, cakes and meals with the addition of protein-polysaccharide stabilizers.

Analysis of literature sources [11–19] indicates significant achievements in the creation of emulsion systems using protein isolates, polysaccharides and natural antioxidants. At the same time, the issue of optimizing the composition of complex stabilizers for the formation of protein-fat emulsion systems resistant to oxidative processes based on flax seeds and soy meal remains unresolved. The main difficulty lies in the selection of stabilizers that are able to provide both mechanical stability and high nutritional value of emulsion systems. Therefore, further research should be aimed at developing a protein-fat emulsion system formulation with an optimal combination of proteins, lipids of plant origin and effective stabilizers.

3. The aim and objectives of the study

The aim of the study is to develop the composition of an emulsion protein-fat system based on oilseeds and secondary products of the oil and fat industry. This will make it possible to create a stable protein-fat emulsion using oilseeds and oilcakes that will be resistant to oxidative deterioration. This will increase the shelf life of the product, while meeting the growing demand for protein-containing products with a high content of PUFA.

To achieve the aim, the following objectives were solved:

– to determine the rational ratio of flax seeds and soybean meal to create a protein-fat base of the emulsion system;

– to substantiate the composition of a complex consistency stabilizer for converting the protein-fat base into an emulsion system;

– to evaluate the physicochemical and technological properties of the resulting emulsion protein-fat system.

4. Materials and methods of the study

4. 1. Object and hypothesis of the study

The object of the study is the technological indicators of the emulsion protein-fat system, developed on the basis of oilseeds and products of its processing. The main hypothesis of the study is the possibility of rationalizing the composition of the emulsion protein-fat system to ensure stability to stratification by controlling the ratio of raw materials and consistency stabilizers.

The following assumptions are made in the study:

– there is a rational ratio of protein and fat components in the composition of the emulsion protein-fat system, which ensures the stability of the system to stratification while maintaining high technological characteristics in the process of production and storage of the product;

– the use of consistency stabilizers in certain concentrations will ensure the necessary stability of the emulsion system.

The following simplification is made in the study: to analyze the stability of the emulsion protein-fat system, the behavior of the lipid phase is chosen as the main indicator. Aspects of microbiological stability and enzymatic processes are also not taken into account, since the study focuses on the physicochemical characteristics of the emulsion protein-fat system and its technological parameters.

4. 2. Materials and equipment used in the experiment

The following materials and reagents were used during the research:

– flaxseed (made in Ukraine) according to DSTU 4967/CAS 8001-26-1;

– soybean meal (made in Ukraine) according to DSTU 4593/CAS 68308-36-1;

– xanthan gum (E 415) (made in China) according to CAS 11138-66-2;

– polyoxyethylene (20) sorbitan monolaurate (polysorbate 80, Twin 80, E 433) (made in China) according to CAS 9005-65-6.

4. 3. Methods for determining the chemical composition of raw materials for an emulsion protein-fat system

The following indicators were determined in the raw material samples:

– moisture content – by drying in a Memmert UF75 drying oven (Germany) according to DSTU 4603;

– protein content – by the Kjeldahl method using a Kjeltec 8400 protein analyzer (FOSS, Denmark) according to DSTU 7169;

– lipid content – by Soxhlet extraction using a Büchi B-811 extractor (Switzerland) according to DSTU 7491;

– fiber content – by filtration after acid-base hydrolysis using a Fibretec 1023 fiber analyzer (FOSS, Denmark) according to DSTU ISO 5498;

– acid number of the lipid component – by titration method according to DSTU ISO 660;

– peroxide value of the lipid component – by titration method according to DSTU ISO 3960;

– fatty acid composition of the lipid component – by gas chromatography method on an Agilent 7890A GC System chromatograph (USA) using a DB-23 capillary column (Agilent, USA) according to DSTU ISO 5508.

4. 4. Method of obtaining model samples of emulsion systems

Model samples of the emulsion protein-fat system were prepared by mixing crushed flax seeds and soybean meal with different proportions to obtain the specified protein:lipid ratios. Coarse grinding of flax seeds is obtained in a laboratory homogenizer IKA ULTRA-TURRAX® T 25 (Germany) for bulk products (speed of about 3000 rpm) to a particle diameter of 500...800 μm. Fine grinding of oilseeds is carried out on a vertical knife grinder model Glasser (Germany) (speed of 8000 rpm) to a particle diameter of 150...200 μm. The samples were added with consistency stabilizers – xanthan gum and polysorbate 80. Before adding to the system, xanthan gum and polysorbate 80 were pre-dissolved in water for 30 minutes at a temperature of 40 °C to achieve complete hydration (concentration in an aqueous solution – 1.0 %). The amount of water in the samples of the emulsion system was 50 % by weight, which provided the prerequisites for the formation of a stable emulsion. The mixture of components was mixed in a laboratory homogenizer at a speed of 5000 rpm. The homogenization process lasted for 5 minutes at a temperature of 40 °C, which allowed to obtain a homogeneous emulsion with a uniform distribution of lipid and aqueous phases. Samples of the obtained emulsions were stored for 7 days at a temperature of 4 °C for further stability analysis.

4. 5. Methodology for determining the stability of model samples of emulsion systems

The stability to stratification of model samples of emulsion systems was determined by centrifugation in an Eppendorf 5810R laboratory centrifuge (Germany) at 5000 rpm for 2 minutes. The appearance of separate phases (aqueous and lipid) was observed and the volume of the separated phases was measured. The percentage of stratification was determined by the volume of the separated phases. The oxidative stability of the lipid phase of model emulsion protein-fat systems was substantiated by analyzing the increase in the peroxide value of the lipid phase, determined on the day of preparation and after 30 days of storage at a temperature of 4 °C.

4. 6. Research planning and results processing

In each experiment described in the work, three repetitions were performed. Experimental data processing and graphical dependence construction were performed using the software packages Microsoft Excel (USA) and Stat Soft Statistica v 6.0 (USA). In studies on determining the dependence (1) of the stability of model samples of the emulsion system on the protein content and lipid content, a two-factor experiment was used. The dependence equation (1) was calculated by approximating experimental data by constructing a trend line. The significance of the coefficients of the approximation equation of dependence (1) was proven by testing the hypothesis of equality of the zero parameters of the equation. The degree of influence of the protein and lipid content of the emulsion protein-fat system on the stability of the emulsion of its model samples was estimated by analyzing the coefficient of determination R^2. The value of R^2=0.978 allows to conclude that the influence of variations in the content of proteins and lipids in the protein-fat base on the variation of emulsion stability is greater than 97.8 %. The significance of the approximation model (1) was determined by comparing the calculated Fisher criterion with its critical tabular value at a significance level of p=0.05 and the corresponding number of degrees of freedom. The results obtained allow to recognize the calculated coefficients of determination for the approximation dependence (1) as significant, and their equation as significant with a probability of more than 95 %.

5. Results of the development of the composition of the emulsion protein-fat system

5. 1. Determination of the rational ratio of oilseeds and cake to create the protein-fat base of the emulsion system

To develop the protein-fat base for the emulsion system, raw materials containing both protein and fat components were selected: flax seeds and soybean meal. Flax seeds are a significant source of ω-3 PUFA, and soybean meal is a source of protein. In addition, it is important to consider that soy proteins have a strong emulsifying ability, so the combination of soybean meal with flax seeds should provide a stable emulsion. The chemical composition of the raw material samples for the protein-fat system is given in Table 1.

Table 1

Chemical composition of raw materials for the protein-fat system

Raw materials	Content, %			
	Moisture	Proteins	Lipids	Fiber
Flaxseed	5.70±0.23	23.50±0.94	43.00±1.29	26.50±1.06
Soybean meal	9.30±0.37	42.70±1.71	1.10±0.03	9.80±0.40

Analysis of the chemical composition of the raw material provides information on its potential for creating a stable emulsion system. A series of experiments were conducted to determine the stability of emulsion protein-fat systems with a consistency stabilizer xanthan gum (0.5 %). The influence of the ratio of raw materials in model samples of the emulsion system (flaxseed and soybean meal) on the stability of the emulsion was determined. The diagram of the specified dependence is shown in Fig. 1.

The content of flax seeds and soybean meal in the emulsion system varied in the range of 0.0...100.0 % with a step of 20 %. The obtained values of emulsion stability of model samples of the emulsion system were within 34...96 %.

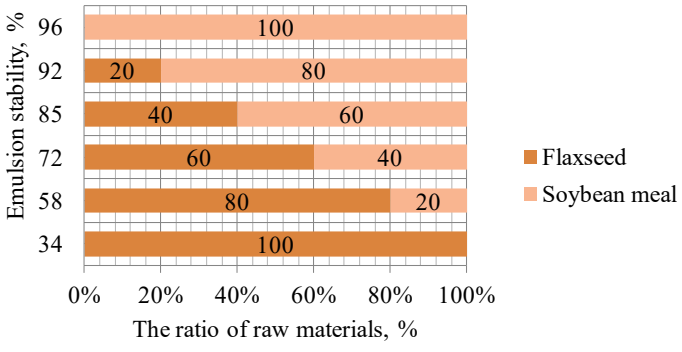

Fig. 1. Dependence of stability of model samples of the emulsion system on the ratio of raw materials

To determine the influence on the stability of model samples of the emulsion system of such parameters as the content of proteins and lipids, the corresponding dependence was studied. Using equation (1), the approximate dependence of the stability of model samples of the emulsion system (ES (c_P, c_L)) on the content of proteins (c_P) and the content of lipids (c_L) is presented:

$$ES(c_P, c_L) = 613.177 - 26.138 \cdot c_P + 56.775 \cdot c_L + \\ +0.328 \cdot c_P^2 - 1.292 \cdot c_P \cdot c_L - 0.693 \cdot c_L^2. \quad (1)$$

This equation reflects the influence of proteins and lipids on emulsion stability, taking into account both linear and quadratic effects, as well as their interaction. The surface of the resulting dependence (1) is shown in Fig. 2.

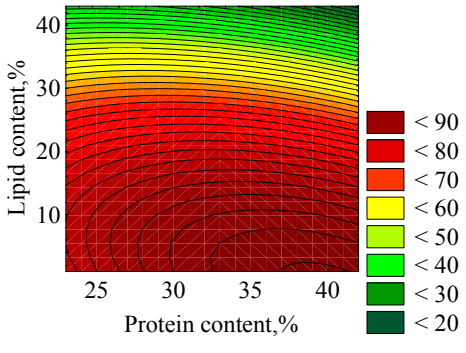

Fig. 2. Dependence of stability of model samples of the emulsion system on protein content and lipid content

It should be noted that the calculated dependence (1), which with the coefficient of determination R^2>0.95, describes the stability of model samples of the emulsion system. This is confirmed for protein content within 23.5...42.7 % (in terms of dry matter) and lipid content from 1.1 to 43.0 % (in terms of dry matter).

The oxidative stability of the lipid phase of model samples of emulsion protein-fat systems with the highest stability was determined: No. 3–6 (Fig. 3). The initial peroxide value of the lipid component of the model emulsion protein-fat systems was practically the same and was 1.60±0.05 mmol ½O/kg.

Based on the results of the study of the oxidative stability of the lipid component of model samples of the emulsion protein-fat system, it was decided to stop our choice on the ratio of raw materials (model sample No. 4):

– flax seeds – 40 %;

– soybean meal – 60 %.

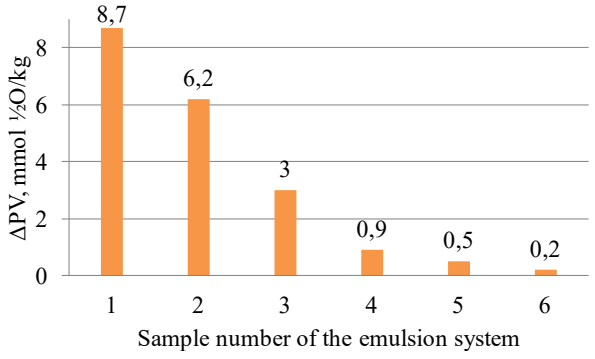

Fig. 3. The increase in the peroxide value of the lipid phase of model samples of emulsion protein-fat systems, determined on the day of preparation and after 30 days of storage

The selected ratio of raw materials has the following advantages:

– high stability of the lipid component to oxidative damage (the increase in the peroxide value is 0.9 mmol ½O/kg);

– high content of the essential nutrient – a-linolenic PUFA – 9.8 %;

– high protein content – 35 %.

5. 2. Justification of the composition of a complex stabilizer for transferring a protein-fat base into an emulsion system

At this stage of the work, the composition of the stabilizing components that ensure the formation and long-term stability of the protein-fat base in the emulsion system is justified: xanthan gum and polyoxyethylene (20) sorbitan monolaurate.

Xanthan gum is used at a concentration of 0.5 %, which has already been determined by previous experiments as a rational value for ensuring the viscoelastic properties of the system. The task of this stage is to determine the minimum concentration of polysorbate-80, which ensures the stability of the protein-fat emulsion system. Stability is achieved by combining polysorbate-80 with xanthan gum for the composition of the components of the protein-fat base (flaxseed – 40 %, soybean meal – 60 %) and the aqueous phase in a ratio of 1:1 (model sample No. 4).

The emulsion stability of model samples of the specified emulsion protein-fat system with different contents of polyoxyethylene (20) sorbitan monolaurate was determined (Fig. 4).

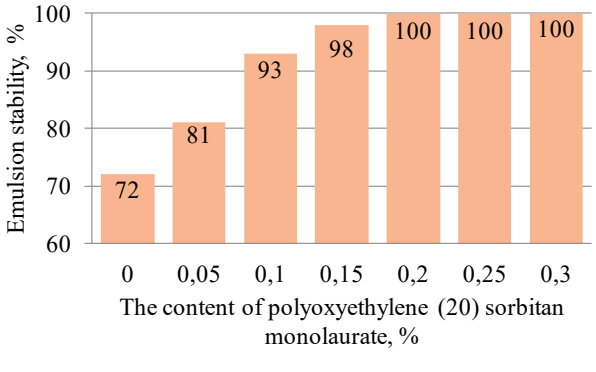

Fig. 4. Emulsion stability of model samples of emulsion protein-fat system with different contents of polyoxyethylene (20) sorbitan monolaurate

Based on the obtained results of the study, the minimum concentration of polyoxyethylene (20) sorbitan monolaurate, which ensures the stability of the emulsion system, was established – 0.20 %. The ratio of consistency stabilizers for the formation of stable emulsion protein-fat systems based on flax seeds and soybean meal is proposed: xanthan gum – 0.5 %; polyoxyethylene (20) sorbitan monolaurate – 0.20 %.

5. 3. Assessment of the physico-chemical and technological properties of the obtained emulsion protein-fat system

A model sample of the emulsified protein-fat system and a comparison sample have been produced, with their compositions presented in Table 2.

Table 2

Composition of the emulsified protein-fat system and the comparison sample

Component name	Content, %	
	Emulsion protein-fat system	Comparison sample
Protein-fat base, including:	50.0	50.0
flaxseed	20.0	0.0
soybean meal	30.0	50.0
Aqueous phase, including:	50.0	50.0
water	49.3	49.3
xanthan gum	0.5	0.5
polyoxyethylene (20) sorbitan monolaurate	0.2	0.2

The physicochemical and technological properties of the emulsion protein-fat system and the reference sample have been determined. Special attention was paid to assessing the stability of the system against oxidative spoilage and the emulsion's resilience.

The obtained samples of the emulsion systems are stable, free from surface films, without signs of component separation, and moderately viscous. After 30 days of storage under the specified conditions, the samples retain their consistency. The results of the physicochemical and technological parameters of the emulsion protein-fat system are presented in Table 3.

Table 3

Physicochemical and technological parameters of the emulsion protein-fat system and the reference sample

Indicators	Protein-fat emulsion system		Comparison sample	
	After preparation (day 0)	Day 30	After preparation (day 0)	Day 30
Protein content, %	35.0±1.1	35.0±1.1	43.0±1.3	43.0±1.3
Lipid content, %	17.7±0.5	17.7±0.5	1.10±0.03	1.10±0.03
including ω-3 PUFAs, %	9.8±0.3	9.5±0.3	0.0	0.0
Fiber content, %	8.20±0.04	8.20±0.04	4.80±0.02	4.80±0.02
Emulsion stability, %	100.0	100.0	100.0	100.0
Acid value of lipid fraction, mg KOH/g	0.100±0.004	0.400±0.008	0.100±0.004	0.200±0.004
Peroxide value of lipid fraction, mmol ½ O_2/kg	1.60±0.06	2.50±0.10	1.5±0.06	1.70±0.07

The emulsified protein-fat system demonstrates higher nutritional value due to its balanced content of proteins (35 %) and ω-3 PUFAs (9.8 %). The lipid content (17.7 %) and fiber (8.2 %) make this system more nutritious and functional compared to the reference sample. A slight increase in peroxide and acid values indicates the effectiveness of stabilizers in preventing oxidation. The reference sample has a higher protein content (43 %) but is significantly inferior in terms of fatty acid composition and fiber, making it less balanced in terms of nutritional value.

6. Discussion of the results of developing the composition of an emulsion protein-fat system

The possibility of developing a protein-lipid emulsion system based on flaxseed and soybean meal was studied. The primary objective was to achieve stability in the emulsion system through an optimal balance of proteins and lipids in the raw materials. Flaxseed was used as a source of ω-3 PUFAs and lipids, while soybean meal provided a high protein content with emulsifying properties.

Analysis of the obtained results (Table 1) reveals significant differences in the chemical composition of flaxseed and soybean meal. Flaxseed serves as the main source of lipids and contains a notable amount of proteins, making it beneficial for emulsion stabilization due to the proteins' film-forming abilities and capacity to stabilize water-lipid phases. However, the emulsifying ability of flaxseed proteins is lower compared to that of soybean meal. The high lipid content, particularly of ω-3 PUFAs, gives flaxseed substantial nutritional value. To ensure emulsion stability, the lipid phase must be protected from oxidation using antioxidants.

Soybean meal, on the other hand, is a primary source of proteins, making it an ideal component for stable plant-based emulsions since soybean proteins possess excellent emulsifying properties. Due to its low lipid content, additional lipid sources are required to create a complete protein-lipid emulsion system.

The impact of proteins and lipids on the stability of the model emulsion system was evaluated through mathematical modeling (Equation 1, Fig. 1). The resulting approximation equation allows for predicting the stability of a model emulsion system containing flaxseed and soybean meal in concentrations ranging from 0 % to 100 %, stabilized by xanthan gum (0.5 %), with protein content between 23.5 % and 42.7 % and lipid content between 1.1 % and 43.0 %.

Equation (1) demonstrates that increasing the protein content positively affects emulsion stability, though a threshold exists beyond which further protein addition does not significantly enhance stability. Conversely, excessive lipid content reduces stability by increasing the risk of phase separation. The component ratio that ensures 96% emulsion stability includes 42.7 % proteins and 1.1 % lipids, aligning with experimental data.

The oxidative stability of the lipid phase in model samples of emulsion protein-fat systems was studied (Fig. 3). The initial peroxide value of the lipid component was practically identical across all samples, amounting to 1.60±0.05 mmol ½O/kg, which indicates a high level of initial stability of the components. Analyzing the obtained results (Fig. 3), it can be noted that

the increase in the peroxide value after 7 days of storage was the lowest in samples No. 4–6. Its value ranged from 0.2 to 0.9 mmol ½O/kg, which is significantly lower compared to samples No. 1–3. This indicator reflects the oxidative spoilage of the lipid phase in the protein-fat system and the oxidative stability of the selected raw material composition.

The chosen raw material ratio in sample No. 4 (flaxseed – 40 %, soybean meal – 60 %) offers several technological advantages. A high protein content (35 %) ensures the stability of the emulsion system and improves its structural properties. Soybean meal serves as a source of proteins with high emulsifying capacity, promoting the formation of a robust protein matrix that stabilizes the water-lipid phase. In turn, flaxseed provides a significant amount of lipids, among which α-linolenic polyunsaturated fatty acid (ALA) constitutes 9.8 %. This fatty acid is an essential nutrient, and its high content enhances the nutritional value of the final product, making it promising for use in dietary and health-promoting food products.

A critical technological aspect is the susceptibility of ALA to oxidative degradation. However, the research results demonstrate that even after 30 days of storage, sample No. 4 maintains the stability of its lipid phase. Compared to other samples, it can be noted that the higher lipid content in samples No. 3 and 5 led to significantly higher peroxide values during storage, indicating more intense oxidation. The most stable samples, No. 5, 6, contained the lowest lipid content, with practically no ALA, which reduced their nutritional value.

Thus, the raw material ratio selected for sample No. 4 is optimal in terms of ensuring the stability of the emulsion protein-fat system and its nutritional value. The high concentration of proteins and ALA contributes to the creation of an emulsion protein-fat system that can be recommended for use in various sectors of the food industry.

The possibility of creating an emulsified protein-fat system was investigated based on flaxseed and soybean meal using xanthan gum and polyoxyethylene (20) sorbitan monolaurate (polysorbate-80) as consistency stabilizers. The selection of consistency stabilizers was based on their ability to ensure emulsion stability against phase separation, improve the rheological properties of the system, and maintain stability during storage. Xanthan gum was chosen as an effective stabilizer due to its high hydration capacity, compatibility with protein components, which enhances the system's texture, thermal stability, and resistance to pH changes. On the other hand, polyoxyethylene (20) sorbitan monolaurate effectively stabilizes emulsions with high water content, interacts efficiently with protein components of the emulsion system, and ensures high emulsion stability across a wide temperature range.

Analysis of the stability results of the emulsion in model samples of the protein-fat system with varying polysorbate-80 content (Fig. 4) revealed significant differences. It was determined that the concentration of polysorbate-80 at a xanthan gum level of 0.5 % significantly influences the stability of the emulsion system in the model samples. The minimum concentration of polysorbate-80 required to achieve maximum stability of the samples was found to be 0.20 %. The selected ratio of stabilizers (xanthan gum – 0.5 %, polysorbate-80 – 0.20 %) is optimal for producing an emulsified protein-fat system with high stability.

This can be explained by the fact that xanthan gum effectively retains the aqueous phase and enhances the viscoelastic properties of the system, while polysorbate-80 acts as an emulsifier that reduces interfacial tension and ensures emulsion stability even under temperature variations. An important aspect is that the chosen ratio of the protein-fat base (flaxseed – 40 %, soybean meal – 60 %) ensures high nutritional value of the emulsified system due to the significant content of ALA (9.8 %) and proteins (35 %).

The relatively high lipid content in the emulsion system makes the use of polysorbate-80 essential for preventing product spoilage by forming a stable emulsion structure, which reduces lipid contact with oxygen and slows oxidative processes. Thus, the obtained results confirm that the use of combined stabilizers at the specified concentrations is an effective way to enhance the stability of the emulsified protein-fat system of the proposed composition, which can be recommended for industrial applications in the food industry.

Analyzing the obtained results (Table 3), it can be noted that the comparison sample contains a higher protein content than the developed emulsion-based protein-lipid system. This difference is attributed to the use of 50 % soybean meal, which has a higher protein content compared to flaxseed. However, the emulsion-based protein-lipid system compensates for the lower protein content by offering a balanced composition of fats and fiber, which may enhance its nutritional value and bioavailability of polyunsaturated fatty acids (PUFAs).

Notably, the emulsion system exhibits a significantly higher lipid content due to the inclusion of 20 % flaxseed, which is rich in fatty acids. In contrast, the comparison sample has an almost negligible lipid component, highlighting its focus on a protein-based composition. The presence of ω-3 PUFAs is unique to the emulsion-based system, attributed to the flaxseed content. These acids are critically important for improving the nutritional value of the product.

A minor reduction (0.3 %) in ω-3 PUFA content over 30 days indicates oxidative processes, but the losses remain minimal, demonstrating the effectiveness of stabilizers such as xanthan gum and polysorbate-80. The higher fiber content in the emulsion system is explained by the presence of flaxseed, which is a significant source of plant fibers. Increased fiber content supports improved digestion and promotes a greater sense of satiety. All samples demonstrate 100 % stability, confirming the effectiveness of the employed stabilizers (xanthan gum and polysorbate-80).

The greater increase in acid value in the protein-lipid system is associated with the presence of ω-3 fatty acids, which are more prone to oxidation. However, the increase remains within acceptable limits, indicating the sufficient efficacy of natural antioxidants present in the plant-based raw materials. A slight rise in the peroxide value in the emulsion-based system reflects the progression of oxidative processes but remains within permissible levels. In the comparison sample, the lower increase is due to its low lipid content, though this results in significantly lower nutritional value for that system.

The development of the emulsion-based protein-lipid system demonstrates distinct differences from previous studies, such as the work in [11], which investigated the use of pomelo fiber and soy protein isolate as a cream substitute in ice cream. That study focused on stabilizing corn oil in oil-in-water systems through gel formation. However, [11] did not address issues related to emulsion stability during storage or the potential use of other plant proteins. In the present development, the primary focus was on creating a protein-lipid

system based on flaxseed and soybean meal, allowing for not only stabilization of the system but also an increase in alpha-linolenic acid (ALA) content, which is critically important for the nutritional value of the product.

The study [13] examines the effects of lipids in different physical states on the gelation of myofibrillar protein, demonstrating that the addition of palm oil enhances the physicochemical properties of the gel. However, the issue of stabilizing protein-lipid systems using plant-based components in vegan products remains unresolved. This research focuses on the combination of soybean meal and flaxseed, enabling the development of a stable protein-lipid base with a high protein content (35 %) and α-LNA (9.8 %). This approach eliminates the need for animal fats and creates a product with improved nutritional properties.

In contrast to study [14], which develops emulsion gels to reduce product caloric content but leaves unresolved questions regarding the optimization of stabilizer composition for emulsion-based protein-lipid systems, this research substantiates the use of heterogeneous stabilizers. Specifically, xanthan gum (0.5 %) and polysorbate-80 (0.2 %) achieve 100 % emulsion stability over 30 days of storage. This confirms the effectiveness of the developed system and its competitiveness compared to existing counterparts. Thus, the results of this research highlight the potential of using emulsion-based protein-lipid systems based on flaxseed and soybean meal to create stable emulsions with an elevated content of valuable ω-3 polyunsaturated fatty acids (PUFAs).

Further exploration of the conditions for applying these findings in the development of emulsion systems for health-oriented food products enriched with ω-3 PUFAs is warranted. Given the high stability of the emulsion-based protein-lipid system, these results can be effectively implemented in the production of sauces, dressings, and creamy products with an increased content of ω-3 PUFAs. This not only ensures structural stability of the emulsion over extended storage periods but also protects the lipid fraction from oxidation, as evidenced by the low increase in peroxide value (0.9 mmol ½O/kg over 30 days). Considering the simplicity of integrating this system into technological processes, such as the production of pasty products and spreads, implementing this development will significantly enhance the nutritional value of finished products. The results are compatible with existing production lines for emulsion-based products, minimizing adaptation costs for the technology.

A limitation of applying the study's findings is that scaling up the production process of the emulsion-based protein-lipid system using alternative plant raw materials or different proportions of flaxseed and soybean meal may necessitate adjustments to stabilizer concentrations. Furthermore, the emulsion's stability, viscoelastic properties, and resistance to oxidation can vary significantly depending on the protein and lipid content in the raw materials. Additional experiments may be required to determine the optimal component ratio and adapt the technological parameters. Moreover, variable storage conditions (temperature, humidity) can influence the texture and sensory characteristics of the final product, necessitating further research and optimization of the technological process.

At the same time, it should be noted that the study has certain limitations, particularly in not addressing the impact of storage duration under various temperature conditions on the stability of the protein-fat emulsion system. The fixation of the storage temperature at 4 °C during the experiment may have limited the ability to assess the dynamics of oxidative processes occurring at elevated temperatures. In the future, it would be advisable to conduct additional research encompassing a temperature range from 0 °C to 20 °C to identify critical points for maintaining the stability of ω-3 PUFAs and the protein matrix of the emulsion system. Particular attention should be paid to studying the rate of peroxide value increase and changes in acid value under prolonged storage conditions, which would allow for more precise determination of the permissible limits for using the proposed stabilizers to extend the shelf life of the emulsion system.

Further improvement of the protein-fat system may involve the addition of antioxidants for enhanced protection of ω-3 PUFAs from oxidation. Additionally, it may be possible to increase the proportion of flaxseed to boost the ω-3 PUFA content, provided that emulsion stability is effectively controlled.

7. Conclusions

1. The chemical composition of raw materials for a protein-lipid emulsion system – flaxseed and soybean meal – was analyzed. It was determined that flaxseed contains 43.0 % lipids, of which a significant portion (57 %) is represented by α-linolenic polyunsaturated fatty acids (PUFA). Additionally, flaxseed contains 23.5 % protein and 26.5 % dietary fiber, which enhances its nutritional value. Soybean meal is characterized by a high protein content (42.7 %) and low lipid content (1.1 %), making it an essential component for balancing the protein content of the system. The optimal ratio of flaxseed (40 %) and soybean meal (60 %) for creating the protein-lipid base of the emulsion system was determined. This ratio provides a high protein content (35 %) and ω-3 PUFA (9.8 %), thereby improving the biological value of the resulting product. It was demonstrated that the selected ratio ensures a minimal increase in peroxide value (0.9 mmol ½O/kg).

2. The composition of a complex consistency stabilizer for forming a protein-lipid emulsion system based on flaxseed and soybean meal was substantiated. It was established that using a combination of xanthan gum (0.5 %) and polyoxyethylene (20) sorbitan monolaurate (0.2 %) ensures the stability of the emulsion (100 %) over 30 days of storage at 4 °C.

3. A comparative analysis of the physicochemical and technological properties of the protein-lipid emulsion system of the developed composition with those of a reference sample (an emulsion system based on soybean meal) was conducted. It was found that the developed emulsion system has a higher lipid content (17.7 % compared to 1.1 %) and ω-3 PUFA (9.8 % compared to 0 %), which enhances the nutritional value of products based on it. The protein content in the developed system is 8 % lower than in the reference sample; however, this is compensated by the balanced fatty acid composition. The fiber content in the protein-lipid emulsion system exceeds that of the reference sample by 3.4 %, positively affecting textural properties and contributing to better stability. The emulsion stability of both systems is 100 %. However, the acid value of the oil fraction after 30 days of storage in the protein-lipid emulsion system is higher (0.4 mg KOH/g compared to 0.2 mg KOH/g), which is associated with the ω-3 fatty acids that are more prone to oxidation. The per-

oxide value of the oil fraction after 30 days is also slightly higher (2.5 mmol ½O/kg compared to 1.70 mmol ½O/kg), but it remains within acceptable limits. This indicates the effectiveness of the natural antioxidants in the raw materials and the stabilizers used (xanthan gum and polysorbate-80).

Conflict of interest

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

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Use of artificial intelligence tools

The authors confirm that no artificial intelligence technologies were used in the creation of this work.

References

1. 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. https://doi.org/10.15587/1729-4061.2023.275509
2. Petik, I., Litvinenko, O., Stankevych, S., Zabrodina, I., Ponomarova, M., Kotliar, O. et al. (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
3. Belinska, A., Ryshchenko, I., Bliznjuk, O., Masalitina, N., Siedykh, K., Zolotarova, S. et al. (2024). Development of a method for inactivating lipoxygenases in linseed using chemical reagents. Technology Organic and Inorganic Substances, 4 (6 (130)), 14–21. https://doi.org/10.15587/1729-4061.2024.309079
4. Kunitsia, E., Kalyna, V., Haliasnyi, I., Siedykh, K., Kotliar, O., Dikhtyar, A. et al. (2023). Development of a flavored oil composition based on hemp oil with increased resistance to oxidation. Eastern-European Journal of Enterprise Technologies, 5 (11 (125)), 26–33. https://doi.org/10.15587/1729-4061.2023.287436
5. Elaine, E., Bhandari, B., Tan, C. P., Nyam, K. L. (2024). Recent Advances in the Formation, Stability, and Emerging Food Application of Water-in-Oil-in-Water Double Emulsion Carriers. Food and Bioprocess Technology, 17 (11), 3440–3460. https://doi.org/10.1007/s11947-024-03350-y
6. El-Sayed, S. M., Hashim, A. F. (2024). Development of emulsion foams based on healthier oleogels and their application as low-fat replacers for whipped cream. Journal of Food Measurement and Characterization, 18 (11), 9142–9155. https://doi.org/10.1007/s11694-024-02866-3
7. Lingiardi, N., Galante, M., Spelzini, D. (2023). Emulsion Gels Based on Quinoa Protein Hydrolysates, Alginate, and High-Oleic Sunflower Oil: Evaluation of Their Physicochemical and Textural Properties. Food Biophysics, 19 (2), 298–309. https://doi.org/10.1007/s11483-023-09817-3
8. Singh, R., Sá, A. G. A., Sharma, S., Nadimi, M., Paliwal, J., House, J. D., Koksel, F. (2023). Effects of Feed Moisture Content on the Physical and Nutritional Quality Attributes of Sunflower Meal-based High-Moisture Meat Analogues. Food and Bioprocess Technology, 17 (7), 1897–1913. https://doi.org/10.1007/s11947-023-03225-8
9. Didar, Z., Khodaparast, M. H. H., Goharjoo, B. (2024). Flaxseed mucilage - stabilized double emulsion for vitamin D delivery in Hazelnut milk ice cream: in vitro stability and storage. Journal of Food Science and Technology. https://doi.org/10.1007/s13197-024-06078-x
10. Zhu, T., Ma, L., Jiang, H., Li, W., Guo, X., Yang, C., Bu, G. (2023). Functional, structural properties of pea protein isolate-xylooligosaccharide glycosylated conjugate and its application in O/W emulsion preparation. Journal of Food Measurement and Characterization, 17 (6), 6135–6143. https://doi.org/10.1007/s11694-023-02102-4
11. Li, X., Zhou, S., Chen, H., Zhang, R., Wang, L. (2024). Pomelo Fiber-Stabilized Oil-in-Water Emulsion Gels: Fat Mimetic in Plant-Based Ice Cream. Food and Bioprocess Technology, 18 (1), 422–432. https://doi.org/10.1007/s11947-024-03446-5
12. Li, H., Zhang, L., Cao, H., Liu, T., Xi, Z., Li, H. et al. (2023). Whey Protein-Based High Internal Phase Emulsion Gel Characterization and Its Effect on the Textural and Melting Properties of Processed Cheese. Food and Bioprocess Technology, 17 (7), 2061–2075. https://doi.org/10.1007/s11947-023-03239-2
13. Sulaiman, N. S., Zaini, H. M., Akanda, M. J. H., Heong, M. H., Chai, A., Pindi, W. (2024). Improving Functionality of Myofibrillar Protein: A Comparative Study on Fat Types on the Resulting Gelling and Microstructure Properties. Food and Bioprocess Technology, 17 (12), 5260–5272. https://doi.org/10.1007/s11947-024-03436-7
14. Ashfaq, A., Osama, K., Yousuf, O., Younis, K. (2024). Protein-based Emulsion Hydrogels and Their Application in the Development of Sustainable Food Products. Plant Foods for Human Nutrition, 79 (4), 759–768. https://doi.org/10.1007/s11130-024-01214-6
15. Lingiardi, N., Galante, M., Spelzini, D. (2024). Development of Bioactive Quinoa Protein Hydrolysate-based Emulsion Gels: Evaluation of Their Antioxidant and Rheological Properties. Food Biophysics, 20 (1). https://doi.org/10.1007/s11483-024-09899-7

16. 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. https://doi.org/10.15587/1729-4061.2020.203664
17. Bui, A. T. H., Cozzolino, D., Zisu, B., Chandrapala, J. (2021). Influence of Fat Concentration on the Volatile Production in Model Whey Protein Systems as Affected by Low Frequency Ultrasound. Food and Bioprocess Technology, 14 (6), 1169–1183. https://doi.org/10.1007/s11947-021-02619-w
18. Kalyna, V., Stankevych, S., Zabrodina, I., Shubina, L., Chuiko, M., Mikheeva, O. et al. (2024). Development of the composition of anoxidation-stable dressing with high nutritional value. Eastern-European Journal of Enterprise Technologies, 1 (11 (127)), 29–37. https://doi.org/10.15587/1729-4061.2024.296621
19. Kunitsia, E., Popov, M., Gontar, T., Stankevych, S., Zabrodina, I., Stepankova, G. et al. (2024). Determination of the influence of hemp oil-based emulsion systems composition on the oxidation products content during storage. Eastern-European Journal of Enterprise Technologies, 3 (6 (129)), 6–13. https://doi.org/10.15587/1729-4061.2024.304466