

Potential areas of using chia seeds meal as part of mincemeat semi-finished products were substantiated. The modern stage of development of the food industry involves the expansion of the range of natural functional ingredients that improve the organoleptic characteristics of finished products and provide consumers with “healthy” food. This causes the use of new ingredients in the meat processing industry for producing and devising products.

The relationship between the indicators of emulsifying capacity, emulsion resistance, and the degree of hydration of chia meal was determined experimentally. It was found that the ability of chia meal to absorb and retain water and fat molecules in the emulsion composition decreased proportionally to a decrease in its concentration in the composition of hydrated samples. The existence of non-polar side chains of amino acids that get bound to fat molecules contributes to an increase in the indicators of emulsifying capacity and emulsion stability during heat treatment (70 ± 2 °C) and after pre-freezing on average by 7–8.7 % and by 16–18.8 %, respectively.

Analysis of effective viscosity of the dispersed system of chia seeds meal indicates that in the area of a higher concentration, the viscous-elastic and solid-like behavior of the suspension depends on dynamic changes in the volume of the phase of particles. Heating the experimental samples to a temperature of 70 ± 2 °C in the center leads to a maximum increase in viscosity of the formed dispersions. When studying the effect of the processes of freezing on the properties of the studied systems, the cryoprotective properties for the proposed additives were detected.

The obtained data indicate the thermal stabilization of the proposed additive, the ability to form a microgel structure in the finished product, and retain moisture during heat treatment of semi-finished products

Keywords: chia seeds, cryoprotective properties, mincemeat semi-finished products, rheological and emulsifying properties

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DETERMINING THE PROPERTIES OF CHIA SEED MEAL GEL

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1. Introduction

The current food trend in developed countries indicates an increase in the consumption of foods that are not only balanced in nutritional value but also easily prepared or “ready to eat”. Modern scientific studies show that many chronic diseases: cancer, cardiovascular diseases, hypertension, obesity, etc., are associated with such “fast” food [1]. That is why consumers increasingly often avoid products that contain preservatives, artificial additives, and lead to weight gain, paying attention to healthy products using natural additives.

With an accelerated pace of life, the demand for frozen food products in the Ukrainian market increased. The main part of the market of frozen products is occupied by mincemeat semi-finished products. Manufacturing this type of product involves pre-freezing, which makes it possible to ensure an increase in shelf life while maintaining quality. However, during freezing, there occur changes associated with the formation of ice crystals in the structure of the product, which, if the process is carried out improperly, can adversely affect the product after defrosting and cooking. This is caused by the fact that crystallization that occurs during freezing is accompanied by destruction of muscle fibers, breakdown of proteins, meat drying up, and affects the properties of defrosted raw materials [2]. Freezing and defrosting

are extremely important technological operations since they make it possible to control and level the functional, chemical, and organoleptic properties of the product [3–5].

To optimize these processes and the quality of the final product, structure-forming agents, stabilizers and emulsifiers are used in the meat-producing industry to eliminate the shortcomings in the production and finished products. Consumers increasingly often pay attention to the natural origin of used additives, so one of the ways of solving this problem is the search for natural structure-forming additives from unconventional plant raw materials [6, 7].

One of the alternatives that have prospects for introduction in the food industry is the use of chia seeds, thanks to their nutritional and medicinal properties [8]. Chia seeds are a natural source of omega-3 and omega-6 (α -linolenic acid), fiber (30 %), characterized by high protein content and natural antioxidants. It is obtained from oilseed Spanish sage. It was found that due to its composition, chia seeds help prevent the development of cardiovascular diseases, inflammation, nervous system disorders, and diabetes [9]. Due to its high nutrient content, it is promising to use chia seeds in the food industry, animal feed, cosmetics, and pharmaceuticals, in particular. The use of dietary fibers of chia seeds can be a useful tool in the development of matrices of structured foods for functional purposes.

Accordingly, a promising area of research is to use chia seeds meal as new ingredients for the meat industry and to determine its effect on the properties of mincemeat semi-finished products.

2. Literature review and problem statement

Chia seeds are small, oval-shaped, flat grains that are from 2 to 2.5 mm long. They range in color from dark brown to black, sometimes gray or white. According to research [10], the chemical composition of chia seeds is represented largely by carbohydrates (about 42 %), 34 % of which are dietary fibers. The value of chia seeds is determined by a high content of fats (30–34 %), which contain a significant part of unsaturated fatty acids, namely alpha-linolenic acid (60 %) [11]. In addition, they contain a relatively large amount of protein (from 16 to 26 %) compared to other traditional cereals, such as wheat, corn, rice, etc. [12]. Another advantage of this type of seed is the high fiber content, about 6 % of which is a fraction of soluble fibers [13]. This made chia seeds an important source of nutrients that is of considerable interest to food science.

The seeds, among other nutrients, contain mucus, which consists of polysaccharides. The authors of [14] found that chia seeds have the capacity to form transparent mucus, and thus retain moisture that is 27 times as much as the mass of the seeds themselves [14]. The studies proved that the mucus formed during soaking corresponds to anionic water-soluble heteropolysaccharide, which is identified as the polymer of β -D-xylopyranoside, α -D-glucopyranosyl, and 4-O-methyl- α -D-glucopyranosiluronic acid. This polysaccharide is a source of soluble fiber and is capable of forming high-viscosity dispersions at a low concentration. This determines digestibility, ability to absorb and deliver other organic compounds, and a positive effect on the human organism at the consumption of chia seeds [15, 16].

The mucus derived from seeds is a potential source of hydrocolloids with various functional properties such as moisture-retaining, emulsifying, foaming ability, solubility in cold and hot water, which is promising for the food industry. Studies [16] indicate that chia seed mucus is characterized by moisture-retaining capacity at the level of 35.2 ± 1.1 g/h. In contact with water, it gets moisturized, swells, and forms a gel system. When combined with proteins, it is able to form edible films, which improves their mechanical and functional properties. Mucus can be used to replace traditional stabilizers in formulations, providing, for example, better organoleptic properties in milk desserts. These articles [15, 16] study only the characteristics of mucus, which is formed on the surface of seeds. In this regard, a significant part of the potentially beneficial components of seeds, such as insoluble dietary fiber and protein, is lost. In addition, no studies on the ability of chia seeds mucus to interact with fat molecules and stabilize the emulsions that are necessary when choosing ingredients for meat products were found. Based on the above data [15, 16], it is advisable to study the properties of chia seeds meal and characterize their prospects for use in the food industry.

Hydrocolloids and protein-containing preparations are the key components of cheaper meat products, and the meat industry always searches for new ingredients with improved functional and technological characteristics for the development of new products. Articles [17, 18] analyzed the properties of mixtures of hydrocolloids with proteins and described

the prospects for their use in the food industry. However, these compositions do not contain fiber, which is one of the important components of human nutrition. Stemming from this, there is the need to find additional promising sources of insoluble dietary fiber and study their properties.

Conducted studies indicate that the fiber and protein content of skimmed chia flour does not differ from other oilseeds currently used in the food industry. In scientific studies [19], the fractions of the flour of chia seeds rich in fiber and protein were characterized via dry fractionation. The authors found that the fraction rich in fiber contained 295.6 g/kg of raw fibers and 564.6 g/kg of the total amount of dietary fiber, 534.5 g/kg of which were insoluble dietary fibers, and 30.1 g/kg – soluble dietary fibers. The protein-rich fraction contained 446.2 g/kg of raw protein, consisting mainly of globulins (64.86 %) and glutelin (20.21 %). The digestibility in vitro for proteins of this product was 77.53 %. The profile of amino acids indicates a high content of essential sulfur-containing and non-essential amino acids, but such amino acids as tryptophan and lysine are in deficit [19].

However, analysis of the above data [10–16, 19], indicates an insufficient level of studying the properties of chia seeds, especially products of its processing (meal) that are rich in protein and fiber.

The meat industry factories produce insufficient mincemeat semi-finished products with the use of raw materials containing a significant amount of food fiber. Dietary fiber in mincemeat and meat and vegetable semi-finished products stabilize their structural and mechanical properties, improve the formation process, exclude the accumulation of fat on the walls of the molding apparatus. In addition, moisture losses during defrosting and heat treatment decrease significantly (by 30–50 %) [20]. Studies [21] established the effectiveness of combining bamboo food fibers and wheat bran with nanocomposite (pyrogenic silica) to improve the structural and mechanical properties of low-calorie semi-finished mincemeat products (effective viscosity of mincemeat increased by 16.5 %).

The functional properties of dietary fibers are also associated with the absorption and retaining of fat molecules, as well as the formation of gel systems. It was found that the addition of dietary fibers to the product that is based on fish meat improves the ability to bind water molecules, emulsifying properties of mincemeat, and the structure of the finished product. This means that the use of similar sources of dietary fiber, such as chia seed meal, can improve the quality of meat products [22].

It is known that mucus from chia seeds and flour of chia seeds was studied for rheological indicators and compared with guar gum and gelatin [23].

Other studies focused on the study of physical and chemical properties and the ability of chia flour and mucus to glue and smear. The results of scanning microscopy demonstrated that chia seeds have a fatty component that covers a significant area of the seed structure, in its turn, fibers are found around the globular structures that can be represented by proteins. The studies of the rheological properties of chia flour showed that the relative viscosity of the systems is mainly determined by the content of fibers and proteins and depends on concentration and temperature. As for chia seeds mucus, its viscosity does not depend on temperature [24].

The viscous-elastic properties of chia seed hydrocolloids were explored by changing transient (structural recovery at shear and creepiness test) and dynamic (change in stress and frequency) of rheological properties. They were determined

at different concentrations of hydrocolloids within 0.5–2 % of mass/mass [25]. Complex viscosity was found to increase at an increase in the concentration of chia seeds gum and to decrease linearly as frequency increases. All samples also demonstrated a typical viscous-elastic reaction to stress in creepiness/recovery tests, in this case, the recovery deformation increased in direct proportion to the concentration of gums. The concentration does not particularly affect the properties of gels from chia seed gum when recovered at shear, and the gel structure is restored significantly after the applied shear force is removed. This made it possible to establish that this type of hydrocolloid is an excellent alternative to polysaccharides already available in the market as thickeners and gel-forming agents.

The studies of the dependence of functional properties on the appearance of chia seeds additives (meal or fiber fraction (fiber) [26] showed its high antioxidant activity due to its high content of phenolic compounds and tocopherol. Chia meal and fiber showed a higher ability to absorb fat molecules, organic compounds, emulsifying activity and allowed obtaining stable emulsions.

However, the issues related to the establishment of the behavior of dispersed systems based on chia meal depending on a change in temperature modes of processing remained unresolved. This makes it difficult to use this additive in the composition of food products, especially mincemeat semi-finished products.

The chia plant and products from it are allowed in the United States (USDA, FDA). In Europe, the possibility of using chia seeds as a new food ingredient was first considered by scientists from the UK [27].

Taking into consideration the experience of the safe use of chia (including children) in the nutrition of the population, the EFSA decision of January 22, 2013, allowed the expansion of the use of chia seeds in mass consumption products. These include bread and pastries, breakfast cereals, fruit, and nut-grain mixtures – in the amount of 5–10 %.

In the bakery industry, chia seed flour is used to bake bread [28]. In study [29], chia seeds flour was added to make a pie. It was found that the level of omega-3 significantly increased in the samples, but the color and taste of the pie, which included chia flour, was much lower.

The results of the studies of restructured hams with a complex of additives from chia and carrageenan seeds are presented in [30]. It was pointed out that the additive increases output and reduces oxidation of lipids and proteins [30], which, if other methods of inhibition of spoilage processes are applied, can extend the shelf life for products with different types of heat treatment [31]. The experience of using chia seeds flour in the amount of 10 % (by substitution of a similar amount of low-fat pork) is known in the meat industry [32].

Analysis of literary sources [10–32] makes it possible to consider the prospects of using the food ingredients that would regulate the nature of crystallization in the composition of frozen mincemeat semi-finished products. Polysaccharides' molecules are known to be the chains rolled up in a tangle, which, in the event of getting into water or in an environment containing free moisture, unwind, thereby limiting the mobility of water molecules. This leads to an increase in the viscosity of the solution [33]. The use of substances or compositions of cryostabilizing action in the technology of frozen meat products is at the stage of development, that is why the scientific literature does not present systematized data on their impact on the properties of meat systems.

The most common additives used in the meat industry as cryoprotectors are hydrocolloids. The study of their properties, such as moisture-retaining, adsorptive and absorptive abilities, as well as the interaction with the lipid fraction, are the main tasks when it comes to the development of new foods. That is why the study of the characteristics of chia seeds meal, containing hydrocolloids, will make it possible to substantiate its purposeful and rational use in industry.

3. The aim and objectives of the study

The purpose of the study is to determine the rheological and emulsifying properties of gels from chia seeds meal. This will make it possible to establish the prospects for its use as a functional ingredient when replacing part of meat raw material in the technology of mincemeat semi-finished products.

To achieve the set goal, the following tasks were to be performed:

- to study the ability of the formed gels to interact with the fat phase by studying the indicators of emulsifying ability and stability of the emulsion;
- to explore the indicators of effective viscosity of gels from chia seeds meal with varying hydration degrees and the effect on a change in effective viscosity of heat treatment of gels;
- to establish the impact of technological operations of freezing–defrosting and heat treatment (bringing to a temperature of 70 ± 2 °C in the center) on the studied indicators and determine a rational hydro module for obtaining gels with high sensory indicators.

4. Materials and methods of research

Chia seeds meal of brand “ZEMLEDAR-INFO” made by TU U 10.41-37183718-002:2017 “Flour, cereals, flakes, bran, and fiber from cereal and oilseeds by separating oil from chia seeds” was chosen as a research object. The cake that remains after the press is ground with the formation of the meal with a particle size of no more than 0.3–0.6 mm. The composition of chia seeds meal is proteins 18 g, carbohydrates 20 g.

Preparation of solutions for research was carried out as follows:

- a sample – chia seeds meal: water in the ratio 1:10, 1:15, 1:20, 1:25 (hydration was carried out by the water at room temperature) – was prepared;
- the resulting gel was divided into three parts;
- the first part was sent for research immediately after preparation at room temperature;
- the second part of the sample was heated in a water bath up to 70 ± 2 °C in the center and cooled to a temperature of 12 ± 2 °C;
- the third part was subjected to freezing to a temperature of -18 °C in thickness, kept at this temperature for a month, defrosted at room temperature until the temperature in the thickness of $0-2$ °C, and sent for research.

The rheological and emulsifying properties were explored in the resulting gel from chia seeds meal.

To study the rheological properties, the indicators of tangent shear stress and effective viscosity were determined.

Tangent shear stress and effective viscosity were determined on the rotational viscosimeter “Reotest-2” in accordance with the manual on its use [34].

To determine the ability of the resulting gels to absorb and retain the fatty phase in their structure, the emulsifying properties, namely, emulsifying ability and stability of the emulsion, were studied.

Emulsifying ability was determined by centrifuging the previously prepared mixture of oil (100 ml), water (100 ml), and gel (7 g) at a rotational speed of 500 s^{-1} for 10 minutes. After that, the volume of emulsifying oil was measured.

Emulsifying ability, %:

$$EA = (V_1/V) \cdot 100, \tag{1}$$

where V_1 is the volume of emulsified oil, cm^3 ; V is the total volume of oil, cm^3 [35].

The stability of the emulsion was determined by heating the resulting emulsion (gel:water:oil) at a temperature of $80\text{ }^\circ\text{C}$ for 30 minutes and cooling with water for 15 minutes with subsequent centrifugation at a rotational speed of 500 s^{-1} for 5 minutes. After that, the volume of the emulsified layer was determined.

Emulsion stability, %:

$$ES = (V_1/V_2) \cdot 100, \tag{2}$$

where V_1 is the volume of emulsified oil, cm^3 ; V_2 is the total volume of emulsion, cm^3 .

The results of the study of emulsifying and rheological properties were expressed as the mean value \pm standard deviation for three-time tests. Statistical analysis was carried out using Microsoft Excel 2007 (developed by Microsoft, USA). The difference is considered significant when $\alpha=0.95$.

5. Results of studying the properties of chia seed meal gel

5.1. Studying the indicators of emulsifying ability and stability of emulsion of the samples of chia seeds meal

Since the proposed additive (chia seed meal) is planned to be used subsequently as a cryoprotector in the technology of meat and meat-based minced semi-finished products, it is advisable to establish its effect on the stability of the meat emulsion. To do this, at the first stage, we conducted the studies of the stability of the water-fat system with hydrated chia seed meal and explored the impact of various modes of treatment on this indicator. The obtained results are shown in Fig. 1, 2.

The demonstrated data (Fig. 1, 2) indicate that the ability of chia seeds meal as part of the emulsion to absorb and retain water and fat molecules decreases in proportion to a decrease in its concentration in the composition of hydrated samples. At the hydration degree of 1:10, the indicator of emulsifying capacity is 42 %, at an increase in the amount of water fraction in the composition of hydrated samples, this indicator decreases by 9.5 %, 19 %, 23.8 %, respectively. As for the emulsion stability indicator (at hydration 1:10 – 34 %), a decrease in this property is 8.8 %, 14.7 %, 23.5 %, respectively, with an increase in the degree of hydration of the samples.

Thermal treatment of samples by heating to a temperature of $70 \pm 2\text{ }^\circ\text{C}$ contributes to an increase in emulsifying capacity at all degrees of hydration on average by 7 %, and the emulsion stability indicator increases by 8.7 %. The

tendency to decrease these indicators in accordance with the concentration corresponds to the previous results of the study of emulsifying properties.

The indicators of emulsifying ability and stability of the emulsion of hydrated samples of chia seeds meal after a pre-freezing increase on average by 16 % and 18.8 %, respectively, compared to the hydrated samples. This indicates an increase in the number of active groups for absorption and retaining fat molecules as part of hydrated samples. As a result of freezing processes, ice crystals that affect the structure of the resulting emulsions are formed.

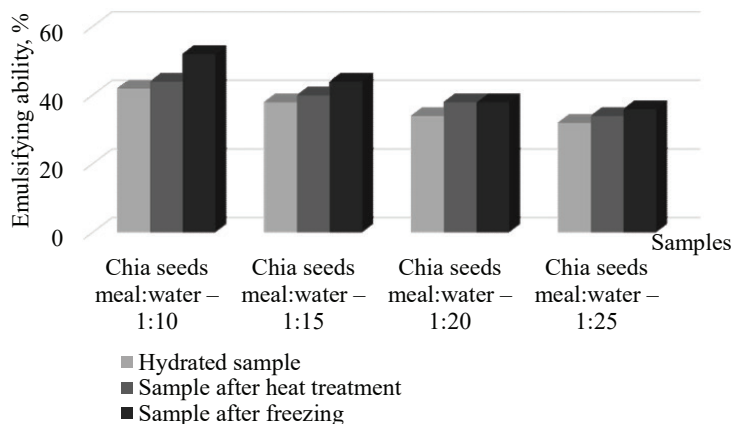


Fig. 1. Dependence of the indicator of emulsifying ability on the degree of hydration of chia meal and treatment methods

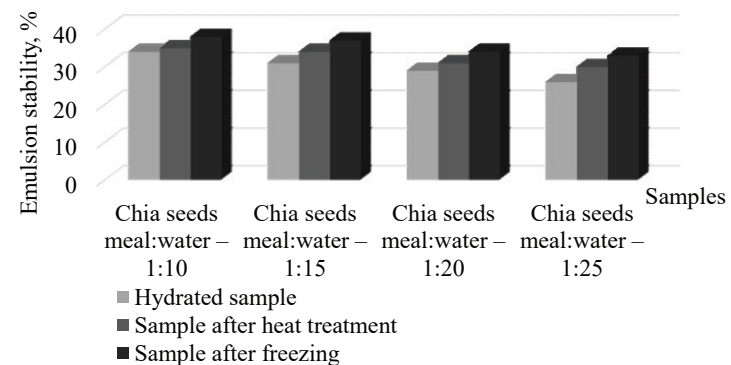


Fig. 2. Dependence of the indicator of emulsion stability on the degree of hydration of chia meal and treatment methods

Comparing the effect of different temperatures on the emulsion stability, it is advisable to note higher results after freezing processes (emulsifying ability increased on average by 9.5 %, emulsion resistance – by 7 %) compared to heat treatment.

5.2. Studying the indicators of effective viscosity and their modification under the influence of heat treatment

The main component of chia seed meal is polysaccharides and proteins, which in the food industry play the role of structure-forming agents and directly affect the rheological characteristics of meat systems. That is why at the next stage, we studied the dependence of indicators of effective viscosity (Fig. 3–6) of hydrated samples on the concentration of chia seeds meal in their composition. We also established a change in these indicators depending on the influence of different temperature modes of treatment (heating and freezing).

Having compared the data shown in Fig. 3–6, we found that indicators of effective viscosity at an increase

in hydration degree decrease by 44.3 %, 75 %, 87.6 %, respectively, compared to the sample hydrated at the ratio of 1:10. The sample of chia seed meal contained dispersion of hydrated microgel particles.

Heating the samples to a temperature in the center of 70 ± 2 °C leads to a maximum increase in viscosity of formed dispersions. The experimental indicator at the hydration rate of 1:10 increases by 56 %, at 1:15 – by 31 %, at 1:20 – by 26.4 %, and 1:25 – by 67.8 %. This indicates the thermal stability of the proposed additive, the ability to form a microgel structure in the finished product, and to retain moisture

during heat treatment of semi-finished products. Studying the effect of low temperatures on the viscosity of the formed system will make it possible to assess the ability of chia seeds meal to preserve the quality of the product during freezing and subsequent processing. The obtained data (Fig. 3–6) indicate the existence of cryoprotective properties for the proposed additive. This is related to a slight fluctuation in the indicator of effective viscosity for research systems at all hydration degrees (at 1:10 it decreases by 16.7 %, at 1:15 it does not change, at 1:20 it decreases by 15.6 % and at 1:25 it increases by 33 %) compared to the untreated sample.

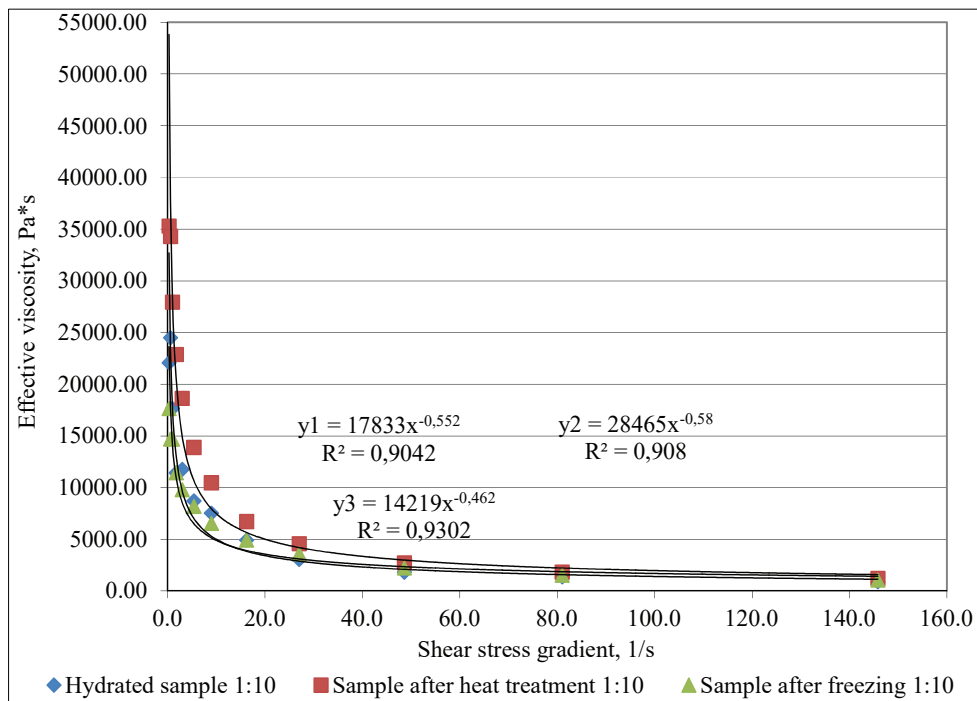


Fig. 3. Dependence of effective viscosity of gel of chia seed meal on shear stress gradient (hydration degree 1:10)

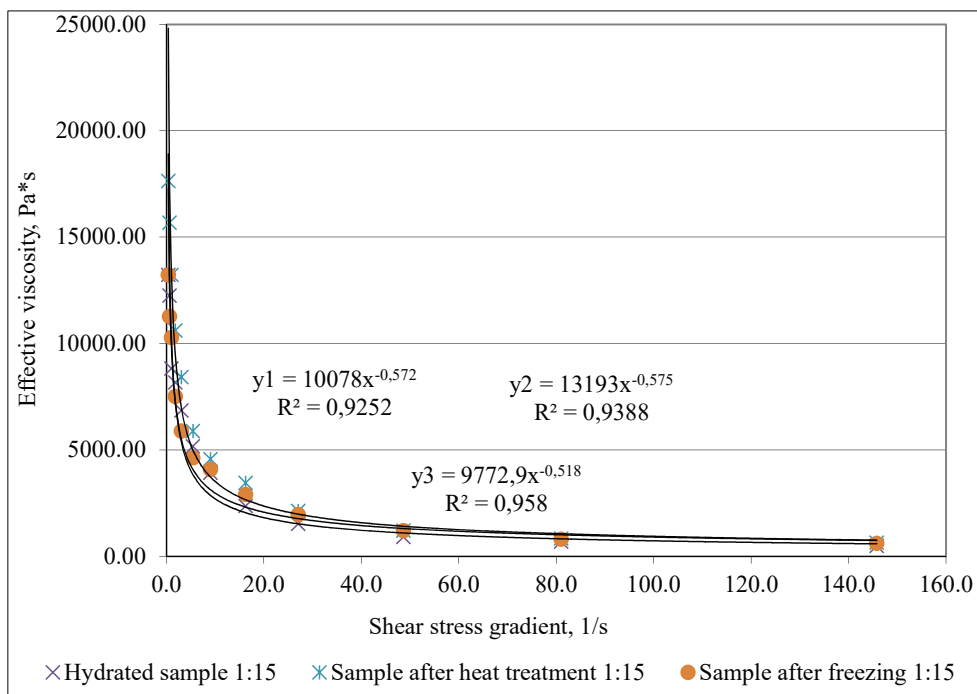


Fig. 4. Dependence of effective viscosity of gel of chia seed meal on shear stress gradient (hydration degree 1:15)

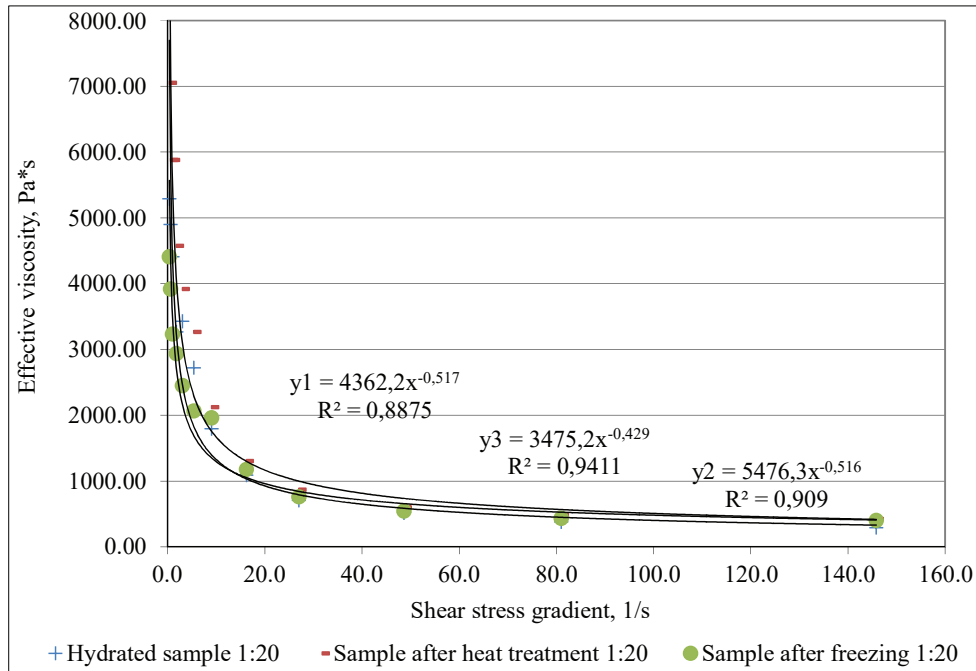


Fig. 5. Dependence of effective viscosity of gel of chia seed meal on shear stress gradient (hydration degree 1:20)

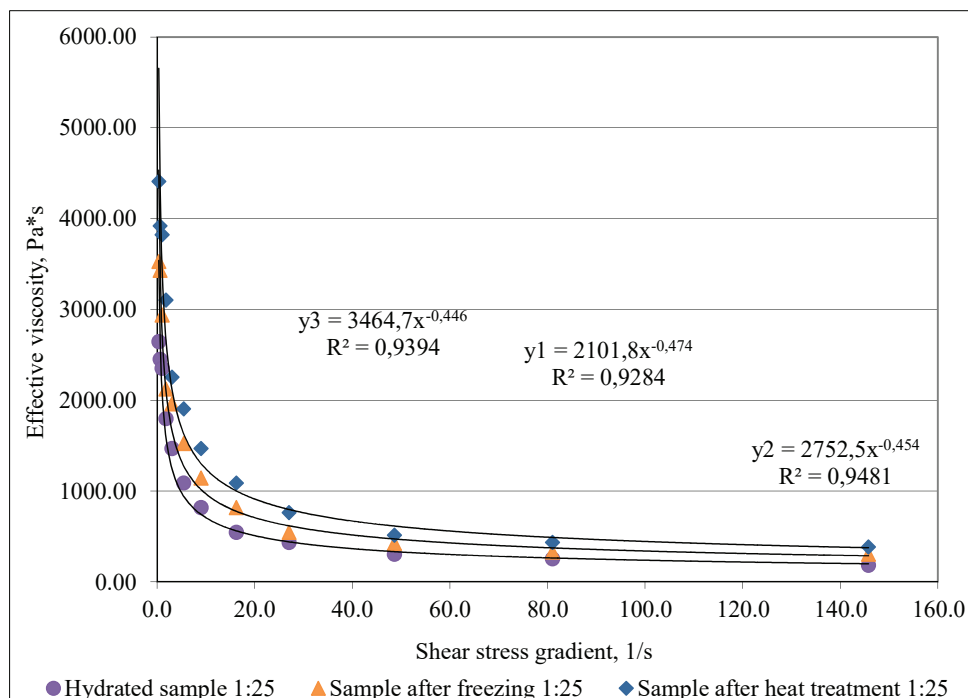


Fig. 6. Dependence of effective viscosity of chia seed meal gel on shear stress gradient (hydration degree 1:25)

It is advisable to note the maximum increase in the indicator of effective viscosity due to the influence of high temperatures (heating up to the temperature in the center of $70 \pm 2 \text{ }^\circ\text{C}$) on the studied systems. It was established that at the degree of hydration of 1:10, the indicator of effective viscosity increases by 87.3 %, at 1:15 – by 31 %, at 1:20 – by 49.7 %, and at 1:25 – by 26.3 % compared to the samples after freezing.

Equations and approximation coefficients shown in Fig. 3–6 testify to the reliability of obtained data ($p < 0.05$).

Like indicators of effective viscosity, the indicator of tangent stress decreases proportionally to an increase in the degree of hydration of the samples.

The studies of the indicator of tangent shear stress made it possible to prove the positive effect of a change in the temperature modes of treatment. We found an increase in the ability to counteract the applied force due to the influence of low temperatures (freezing) compared to untreated samples. The maximum increase in the indicator of tangent shear stress is characteristic after heat treatment at all hydration degrees (an average of 46.5 %) and corresponds to the data obtained in the study of indicators of effective viscosity. The indicator of tangent shear stress increases after the processes of heat treatment and defrosting/freezing, which has a positive effect on the properties of the chia seed gel.

5.3. Studying the influence of technological operations of freezing-defrosting and heat treatment on the properties of chia seed meal gel

The resulting dispersions after preparation and stilling showed the ability of gel formation. To determine the effect of the concentration of chia seeds meal and temperature modes of treatment on the stability of the formed gel systems, its characteristics were studied visually (the data are given in Table 1).

Table 1

Effect of freezing-defrosting and temperature treatment on sensory characteristics of the gel

Hydrated dispersion from chia seeds meal	View		
	Prepared gel	After freezing	After heat treatment (heating up to a temperature in the center of 70 ± 2 °C)
Hydration degree 1:10	Homogeneous, durable, stable gel with patches of chia seeds particles	Solid, stable gel, in some places frozen gel comes off the walls, a film is formed on tank walls	Homogeneous, stable gel with a solid, strong structure with patches of particles of chia seeds shell
Hydration degree 1:15	Homogeneous, stable gel with patches of particles of chia seeds shell, destroyed by mechanical stress	Stable gel, in some places frozen gel comes off the walls, a film is formed on tank walls	Homogeneous, solid gel with a stable structure with patches of particles of the chia seed shell
Hydration degree 1:20	Homogeneous gel of loose structure with patches of particles of chia seed shell, no sediment	Homogeneous gel of loose structure	Homogeneous, stable gel with patches of particles of chia seeds shell, destroyed by mechanical stress
Hydration degree 1:25	Homogeneous, ointment-like system with patches of particles of chia seed shell, no sediment	Thick gel of loose structure	Homogeneous stable gel with patches of particles of chia seed shell, of loose structure

Similar to the previous studies of effective viscosity (Fig. 3–6), we pointed out a decrease in the strength of the formed gel at an increase in hydration degree. Analyzing the effect of changes in temperature modes of treatment on the stability of gel systems, it is advisable to note the formation of a stronger structure as a result of heating of the samples.

The influence of low temperatures (freezing) made it possible to improve the structure of the formed gel at all hydration degrees, but the samples are inferior to the gels formed after heat treatment.

6. Discussion of the results of research into the properties of chia seeds meal gel

Analyzing the obtained data (Fig. 1, 2) on studying the behavior of chia seeds meal as part of emulsions, we noted its ability to retain water and fat molecules, regardless of changes in temperature modes of treatment. The obtained

results (Fig. 1, 2) are partially related to the high protein content in the composition of chia seed meal since most proteins are strong emulsifying agents. However, according to the known chemical composition, this additive contains a high amount of carbohydrates (fiber), and taking into consideration the indicators of emulsifying capacity and emulsion stability, we can assume that they also play the role of an emulsifying agent.

The ability to interact with organic molecules can also be caused by the content of lignin in chia fiber. That is why chia seeds with a high content of insoluble dietary fiber absorb organic molecules more efficiently. The data presented in Fig. 1, 2, make it possible to recommend the use of this additive as an emulsifying agent in the composition of long-term meat products.

The tendency to change the indicator of effective viscosity depending on the concentration of chia seeds meal as part of the dispersion is proved by similar studies of other scientists [6]. They pointed out that a decrease in this indicator is observed at a decrease in the concentration of the dispersed substance and an increase in the dispersion medium in the composition of hydrated samples and meet the obtained data (Fig. 3–6). These results (Fig. 3–6) reveal the non-Newtonian behavior of the system. Viscosity shows a directly proportional ratio to concentration and decreases as the shear rate increases, which leads to liquefaction of the system during shear. This behavior is explained by the fact that at an increase in shear rate, partially destroyed chains of hydrocolloids become oriented and straightened, which leads to a decrease in viscosity. Accordingly, dispersions show pseudo-plasticity, non-Newtonian behavior, even at low concentrations that correspond to the results of previous studies [16, 27].

Based on the obtained results (Fig. 3–6), we can conclude that the rheological properties of such dispersions give many advantages in ensuring varying degrees and stabilization mechanism in food systems.

Heat treatment (heating to a temperature in the center of 70 ± 2 °C) led to an increase in the effective viscosity of the research systems. The obtained data (Fig. 3–6) indicate the beginning of the formation of a “more stable gel” structure of the dispersion of chia seeds polysaccharides. It is believed that this behavior of the gel is due to the elasticity of the swelling parts of microgels dispersed in the fraction of soluble components that form a weak transitional gel network connected by the physical contacts of adjacent parts (molecules). The behavior of such a system during the shear showed insignificant thixotropy. Interactions between the swollen insoluble microgel particles that are placed in the formed structure can be ruined, but after stress is removed, they return to their previous state. This property has potential use for products with the need to preserve the structure after applied mechanical impact.

The obtained data (Fig. 3–6) on the study of the effect of low temperatures (freezing) on the structure of the samples from chia seeds meal can be explained by the high ability to absorb and retain water molecules in the structure. This contributed to a decrease in the amount of available water for the formation of ice crystals and the destruction of the structure that causes the moisture separation after defrosting and affects the quality of the studied samples.

The obtained viscosity curves (Fig. 3–6) have the shape characteristic mainly of the elastic system, indicating visco-elastic behavior of the samples. This means that as a result of exposure to low temperatures, there was a certain restructuring of the gel, which explains the results.

The studies of the influence of different modes of temperature treatment revealed a modification of indicators of effective viscosity of the samples, which consisted in the increased property. This accordingly indicates thickening of the studied system and the formation of more stable and stronger bonds between molecules of chia seeds meal. The influence of temperature increases viscosity characteristics, which is more observed in solutions with a higher concentration. This makes it possible to assert that this system will improve viscosity characteristics both at the production stage and in the finished product.

The obtained results of the study of the stability of the obtained gels (Table 1) coincide with the data on the study of rheological characteristics. The identified “gel-like” properties of dispersions from chia seeds can be manifested through an association of ordered fiber and protein chains and reflect the pronounced elastic behavior and strong branching of the network in the experimental system. This indicates an increase in the hardness of the continuous phase due to the thickening effect. However, it differs from the obtained data on the study of the emulsifying ability of the samples, which is associated with a decrease in hydrophobic groups as a result of associations between molecules in the middle of the structure. The analyzed data (Table 1) coincide with the previous results of the study of emulsifying and rheological properties. They may be due to the formation of polydisperse, fibrous irregularly shaped microgel particles after freezing and the absence of stitching between molecules as a result of heat treatment.

The study of emulsifying and rheological properties of chia seeds meal will make it possible to predict the effect of this additive on the stability of meat emulsions and rationally determine the amount of its application. However, depending on the conditions of production and its capacities, different batches of chia seeds meal may differ in fractional composition. In the end, this may slightly change the properties of the obtained additive and affect the quality of the final product. In this regard, the use of this additive requires constant analysis of its properties and determining the rational amount that should be added. To provide the overall character of this additive, it is advisable to study its behavior

as part of meat products and establish its ability to stabilize the formed structure.

7. Conclusions

1. Based on the study of emulsifying properties of hydrated samples of chia seeds, it was found that heat treatment stabilizes the formed emulsions and increases the emulsifying ability and emulsion stability by 7 and 8.7 %, respectively. The maximum values of the studied samples were observed after the samples were frozen (the indicator increases by 16 % and 18.8 %, respectively), which indicates the ability of chia seed-based gels to ensure the stability of the structure of the finished product.

2. The study of indicators of effective viscosity of the suspension based on chia seeds proves the positive effect of temperature modes of treatment on an increase in viscosity, and therefore improvement of the structure of the formed dispersions. There is an increase in the indicator of effective viscosity as a result of heat treatment and a slight impact of freezing on this indicator.

3. Visual analysis of the formed chia seeds meal gels made it possible to prove the existence of stabilizing and structure-forming properties of the selected additive. Improvement of the gel-forming ability of dispersions as a result of various types of the treatment proves the possibility of its use in the composition of frozen mincemeat semi-finished products as a stabilizer and a structure-forming agent.

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