UDC 664.144: 635.7
DOI: 10.15587/1729-4061.2024.318530

APPLYING CHIA SEEDS TO IMPROVE THE STRUCTURAL CHARACTERISTICS AND NUTRIENT COMPOSITION OF WHIPPED CANDIES

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The object of this study is the technology of whipped candies with the introduction of whole and crushed chia seeds. Whole seeds were added at the stage of whipping the protein (% of the mass of dry egg albumin), and crushed seeds were added during the preparation of the milk-fat mixture (% of the mass of fat). The introduction of the additive solves the task of improving the structural characteristics of whipped candy masses and candies made on their basis. The issue of improving the nutritional composition of products has also been resolved.

It was established that the introduction of whole chia seeds (up to 50 % of the mass of dry egg albumin included) contributes to the improvement of the foaming of brewed protein masses during whipping and to the reduction of their density. Increasing the dosage of chia causes the deterioration of these indicators. In view of this, it is recommended to limit its dosage to 50 % of the weight of dry albumin when adding whole seeds to the brewed whipped protein mass.

It was noted that when adding whole/crushed chia seeds in the amount of (50/40) %, (50/50) %, and (50/60) % of the mass of dry albumin/fat, the viscosity of unstructured candy masses increases slightly. Due to this, the duration of their structure formation is reduced, and the rate of shrinkage decreases. Whipped candies from such masses, compared to the control ones, are characterized by higher values of adhesion, strength, and density indicators. However, the visual deterioration of the porosity and compaction of the structure is characteristic only of the samples with the content of whole/crushed seeds (50/60) %. That is, the rational dosage of whole/crushed chia seeds is (50/50) % of the weight of dry albumin/fat.

Such products are characterized by improved nutrient composition. In particular, the content of proteins and non-starch polysaccharides increases, the balance of fats improves, and the content of micronutrients such as polyphenols, minerals, and vitamins increases significantly

Keywords: whipped candy technology, chia seeds, structural characteristics, nutrient composition

Received 07.10.2024
Received in revised form 29.11.2024
Accepted 11.12.2024
Published 27.12.2024

How to Cite: *Shydakova-Kameniuka, O., Zagorulko, A., Kasabova, K., Mikhaylov, V., Shkliaiev, O., Rohova, A., Novik, A., Lapytska, N. (2024). Applying chia seeds to improve the structural characteristics and nutrient composition of whipped candies. Eastern-European Journal of Enterprise Technologies, 6 (11 (132)), 73–83. https://doi.org/10.15587/1729-4061.2024.318530*

1. Introduction

The UN approved a sustainable development strategy [1] and approved 17 goals for its implementation. Goal No. 2 "Overcoming hunger" includes, in particular, guaranteeing food security and creating sustainable food production systems. One of the elements of food security is people's access to a sufficient amount of food, which should be safe for health and contain all the substances necessary for the normal functioning of the body. From 2021, there has been an aggravation of the problem of ensuring food security due to the COVID-19 pandemic, martial law, and certain climatic cataclysms [2]. The consequence is the increase in the number of non-infectious diseases: cardiovascular, metabolic disorders, etc. To improve the level of food security and fight against non-communicable diseases, it is important to spread the introduction of healthy food. Sustainable food production systems (sustainable food systems), including the use of raw materials obtained with the involvement of such methods of agricultural management, do not apply polluting practices and contribute to the preservation of ecosystems [1]. In general, the concept of "food systems" unites all actions related to the production and consumption of food products, as well as the impact of these actions on human health and the environment. In view of the above, research is of interest on ensuring food safety and enriching it with nutrients important for the normal functioning of the human body, and with the use of raw materials obtained under proper agricultural practices.

Chia seeds (*Salvia hispanica L.*) could become a promising type of such raw materials. The peculiarity of growing chia seeds is its unpretentiousness. This culture is quite resistant to pests, withstands drought, can grow on soils poor in nutrients. That is, *Salvia hispanica L.* is suitable for organic farming. In addition, the cultivation of chia on an industrial scale is carried out in strict compliance with the principles of good agricultural practice [3]. Chia seeds are known for their high nutritional and biological value, which determines their significant potential for providing sustainable nutrition and prevention of non-communicable diseases [4]. It has been proven that chia seeds exert an immunomodulating, antioxidant, and antimicrobial effect on the human body [5]. It also has anti-inflammatory, hypolipemic, and hypoglycemic properties, improves digestion, has a hepatoprotective and anti-nephrolytic effect, etc. [6]. This led to the approval of chia seeds as a new food by the European Parliament in 2009 [6] and since then its popularity has continued to grow.

The peculiarities of the chemical composition of chia seeds determine not only their high nutraceutical potential but also the manifestation of their functional and technological properties: water-retaining, fat-emulsifying, foam-stabilizing, etc.

That is, scientific research on expanding the range of use of chia seeds is important not only for the fortification of food products but also for the regulation of their technological and structural characteristics.

2. Literature review and problem statement

Two main areas of application of *Salvia hispanica L.* in the food industry can be distinguished. The first direction involves the extraction of mucilaginous substances from chia seeds for their further use in order to stabilize the structural characteristics of food systems. The second direction is focused on the complex use of nutraceutical and technological potential of chia seeds. This is achieved by introducing it to various technologies in its native state or in the form of processing products that do not involve significant changes to the seed – in a crushed state.

Considerable attention of scientists is focused on the use of chia mucous substances directly in various food technologies. It was established that these heteropolysaccharides, the amount of which is 5...10 % of the total dietary fiber content of the seed [6], are responsible for its hydrophilic properties. Mucous substances include fibrous materials. During swelling in water, they stretch out, go beyond the seed through the pores in the shell and combine with each other, forming a spatial network. In the cells of such a grid, hydrophilic groups of mucous substances hold water (in the amount of 7...27 units in relation to its weight), which is visually manifested in the formation of a viscous gel [7, 8]. Such a gel in its native or dehydrated state can successfully compete with other hydrocolloids used in the food industry as structure formers [9].

A number of works have established the high potential of chia seed slime as an emulsifier, fat, or egg substitute. Thus, it is recommended to replace up to 75 % of oil with a suspension of dry chia mucilage extract in bakery technology [10]. During the production of sausage products, it is suggested to use reconstituted chia seed gel to replace 50 % of fat [11] or to replace synthetic emulsifiers [12, 13]. Study [14] justified the complete replacement of eggs with such a component in brownie technology for vegetarian food.

Using mucilage from chia seeds has certain advantages. In particular, during their production, components with the required functional and technological properties are purposefully isolated, which ensures their targeted use in various food technologies as structure-builders, substitutes for fatty or egg raw materials. The disadvantage of the processes of extraction of mucous substances is their complexity. In addition, most current research is limited to obtaining laboratory samples of these substances. As a result, their commercial forms are not available in the market, which makes their use on an industrial scale impossible. Issues related to the improvement of the nutritional composition of products also remained unresolved – after the removal of mucus, the main useful substances remain in the separated seeds. As a result, another problem is the issue of further use of such seeds, which have a high nutritional value. Thus, researchers have not provided suggestions for its use. In view of this, it is more promising to add chia seeds to food products as a whole, in crushed form, or in the form of flour.

The most common use of chia seeds is to improve the quality characteristics of flour products. Thus, it was established that the addition of chia seed flour (5 % of the weight of wheat flour) [15] or pre-hydrated whole seeds (5 and 7.5 %, respectively) [16] improves the structural and mechanical properties of wheat dough and ready-made bread. The addition of up to 10 % of whole chia flour has a positive effect on the quality of gluten-free bread based on rice flour [17]. The shortcoming of the research is the low dosage of chia seeds and its processing products, which does not provide an opportunity to significantly improve the nutrient composition of products with their use. The likely reason is objective difficulties associated with the peculiarities of the formation of the structure of bakery products. High dosages of chia and its products have a negative effect on the gluten of wheat flour or worsen the process of forming the porosity of such products due to their significant density.

The best option may be the use of the specified additives in the technologies of flour confectionery products, for which the deterioration of gluten quality does not have a negative effect on the quality of finished products. In particular, replacing 20 % of wheat flour with whole chia seeds in its technology showed a good result in terms of improving the structural properties and nutritional value of shortbread cookies [18]. And in work [19], it is proposed to use ground chia seeds (defatted and non-defatted) in the amount of up to 15 % of the mass of flour in the technology of long-lasting cookies of the "Maria" type. Not only the improvement of the structural properties of the products was noted but also a significant increase in the amount of phenolic compounds and an increase in antioxidant activity. In study [20], it is recommended to replace 25 % of the fat with pre-hydrated whole chia seeds when making cupcakes. This makes it possible to obtain products with reduced energy value, improved chemical composition and textural characteristics preserved at the level of the control sample. That is, it is possible to use higher dosages of chia seeds and its processing products in flour confectionery technologies than in bakery products. This makes it possible to more fully realize its nutraceutical potential.

The weakness of the studies reported above is that the considered technologies involve the use of high temperatures during baking of products. However, recent studies have established that the use of heat treatment leads to the formation of acrylamide in chia seeds [21], which is a potential human carcinogen. In view of this, in 2019, the European Food Safety Agency (EFSA) recommended limiting the use of chia seeds to products in which they would not be subject to significant thermal effects [22].

An option for solving such a problem can be the introduction of chia seeds into the technology of whipped candies. The process of their production involves brewing the whipped protein mass with sugar syrup with gelling agent at a temperature of 65...67 °C, combining the mass with other components, forming a structure, cutting into cases, and glazing. At this temperature, firstly, the formation of acrylamide does not occur, and secondly, the useful substances included in the composition of the seeds are preserved almost in their native state. In addition, whipped candies are in steady demand among consumers from various age groups.

In order to improve the structural properties of whipped candies and fortify them with useful nutrients, it is suggested to add fruit and berry raw materials to their composition. For example, works [23, 24] recommend adding apple, quince, and blackcurrant paste (15 % of the total amount of raw materials). And in work [25] – replace molasses with cherry (or pomegranate, or grape) juice.

The weakness of the proposed methods is the sufficiently high humidity of such additives. On the one hand, this leads to a low concentration of physiologically important nutrients in them, and on the other hand, it limits their dosage due to the diluting effect on the structure of the products.

All this allows us to state that it is appropriate to conduct a study on the possibility of using chia seeds during the production of whipped candies. Previous studies have established that chia seeds have a good technological potential for use in the technology of whipping candy masses. In particular, the whole seed improves the foaming process during whipping of egg albumin and increases the stability of such masses. Crushed chia seeds have high fat-retaining properties and have a positive effect on fat emulsification [26]. This was the basis for the recommendations of adding whole chia seeds to the technology of whipped candy masses at the stage of obtaining the whipped protein mass, and crushed seeds at the stage of preparing the milk-fat mixture [26, 27]. The issue of assessing the structural and mechanical properties of semi-finished products for whipping candy masses with different dosages of chia seeds and the quality indicators of finished candies obtained from them remained unresolved. That is, it is appropriate to conduct a study on the use of whole and crushed chia seeds in the technology of whipped candies to improve their structural, organoleptic properties, and fortify them with useful substances.

3. The aim and objectives of the study

The purpose of our study is to determine the possibility of using chia seeds to improve the structural characteristics and nutrient composition of whipped candies. This will ensure the expansion of the range of sugar confectionery products fortified with physiologically useful substances.

Within the framework of the set goal, the following tasks have been defined:

– to analyze the quality indicators and properties of chia seeds used in research;

– to investigate the effect of whole chia seeds on the quality of brewed whipped protein mass;

– to analyze the effect of whole and crushed chia seeds on the quality of unstructured whipped candy masses and the quality of candies made from them (structural characteristics, organoleptic properties, and nutrient composition).

4. The study materials and methods

The object of our study was the technology of whipped candies made on agar or pectin with and without the addition of whole and crushed chia seeds. The hypothesis of the research assumes the possibility of obtaining whipped candies with improved structural characteristics, high organoleptic indicators, and improved nutrient composition through the introduction of chia seeds. The use of chia seeds will also ensure the expansion of the range of candy products fortified with physiologically useful substances.

Research materials:

– chia seeds;

– samples of brewed whipped protein mass with and without the addition of whole chia seeds;

– samples of structured whipped candy masses with and without the addition of whole and crushed chia seeds.

The control was samples of whipped candy masses, made using the "Classic Bird's Milk" technology.

Recipe components for making candy masses on agar (or pectin*) are taken in the following ratio, %: condensed milk – 12.26 (11.67*), margarine – 25.89 (25.95*), dry egg albumen – 0 .90 (0.90*), citric acid – 0.26 (076*), vanillin – 0.40 (0.40*), sugar – 40.6 (40.04*), molasses – 20.03 (19.49*), agar (pectin*) – 0.26 (1.15).

The main stages of making samples of whipping candy masses for research are shown in Fig. 1.

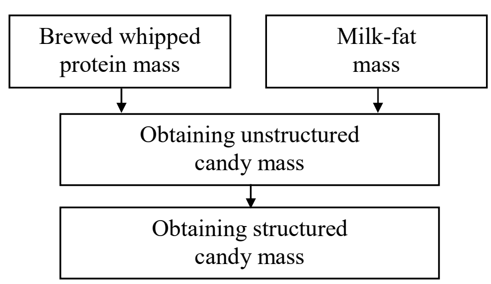

Fig. 1. Schematic diagram of the production of whipping candy masses for "Bird's milk classic" candies

The introduction of whole chia seeds was carried out at the stage of production of whipped protein mass in the amount of 30, 40, 50, and 60 % of the mass of dry egg albumin. To prepare samples of whipped protein mass, dry egg albumin was hydrated in water for 10 min at a hydro module of 1:7. Chia seeds were added to the hydrated albumin, left for 10 minutes to swell, and whipped for 20 minutes.

In order to obtain samples of brewed whipped protein mass, hot (t=63...67 °C) syrup with gelatinizer (sugar-agar-molasses or sugar-pectin-molasses) was added to such a mixture with a thin stream while constantly stirring for 12±2 minutes (Fig. 2).

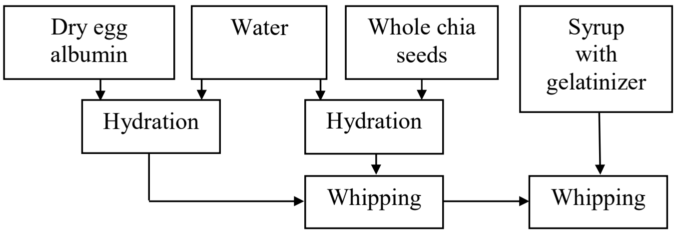

Fig. 2. Schematic diagram of the preparation of brewed whipped protein mass with chia seeds

Crushed chia seeds were added at the stage of production of milk-fat mass in the amount of 30, 40, 50, and 60 % of the mass of fat (Fig. 3).

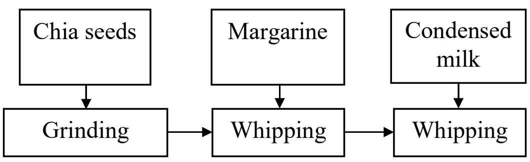

Fig. 3. Schematic diagram of the preparation of milk-fat mass with crushed chia seeds

The obtained milk-fat mass was mixed with the brewed protein mass. The finished cream-whipped candy mass was formed by the spreading method. To evaluate the strength, the mass was poured into chemical beakers in 30 ml increments. Structure formation was carried out at a temperature of 19...21 °C for 60 minutes.

The experiment used dark chia seeds of the 2022 harvest, the country of origin is Mexico.

Grinding of chia seeds was carried out on a PG1000 laboratory mill. The degree of grinding of seeds was assessed using a "Biolam" microscope (120x magnification), the size of particles was determined by calculations using the PhotoM digital photo software.

To determine the active acidity (pH), chia seeds were crushed, mixed with distilled water (1:20), and the pH value was determined by the potentiometric method. The moisture content of chia was determined by drying to constant weight.

The water-holding capacity of whole and crushed chia seeds was determined at different ratios of chia seeds:water. To determine the value of the water-holding capacity index, chia seeds were combined with water, kept for 600 s, and centrifuged according to the method described in [28]. The water-holding capacity (in %) was determined by the ratio of the difference between the amount of water taken for the experiment and the mass of fugat obtained after centrifugation to the mass of the used batch of whole or crushed chia seeds.

The coefficient of foam formation of brewed whipped protein mass was determined by the ratio of the volume of the whipped mass to its initial volume [29]. The density of the brewed whipped protein mass and the density of ready candies were calculated by the ratio of the mass of the sample to its volume. The viscosity of unstructured candy masses was determined on a Reutov rotary viscometer. Shrinkage during structuring was calculated as the ratio of the volume of the structured sample to its volume before structuring and expressed as a percentage.

The strength of candies was determined by the destructive load (in grams), which was established on the Valenta device.

The adhesion index of candies was evaluated using an adhesiometer based on the force of separation of the product from the surface of the plate of the rod of the device.

The calculation method was used to assess the nutritional composition of ready-made candies. During the calculation, known data on the chemical composition of chia seeds were used [6].

The organoleptic evaluation of the samples was determined by the expert method, 8 experts participated in the research.

Statistical processing of research results was carried out for a series of parallel measurements (n=4–5, p<0.05).

5. Results of research on the properties of chia seeds, quality indicators of semi-finished products for whipped candies and finished products

5. 1. Results of research on the properties of chia seeds

The characteristics of the chia seeds used in the research were evaluated (Tables 1, 2, Fig. 1).

Table 1

Quality indicators of chia seeds used in research

Organoleptic			Physicochemical (n=4, σ=3...4 %)	
Appearance	Taste	Flavor	Humidity, %	pH, units
A mixture of oblong seeds of different colors (white, gray, brown), length – 1 ... 2 mm	Slight pleasant nutty flavor	Neutral	4.6	5.9

It has been established that chia seeds have low humidity and a slightly acidic environment. Since it is envisaged to use chia seeds not only as a whole but also in a crushed state, the granulometric composition of the crushed seeds was evaluated (Table 2).

Table 2

Granulometric composition of crushed chia seeds

Particle size distribution of crushed chia seeds (in %), µm						Average particle diameter, µm
to 80	80...110	110...140	140...170	170...200	200...230	
3	6	19	40	26	6	153.7±4.2

It is noted that grinding the seeds yields a powdery mass with an average particle size of about 154 µm. At the same time, the amount of seeds crushed into particles 110...200 microns in size is 85 %.

For whole and crushed chia seeds, the indicator of water-holding capacity was determined for different ratios of chia seeds:water (Fig. 4).

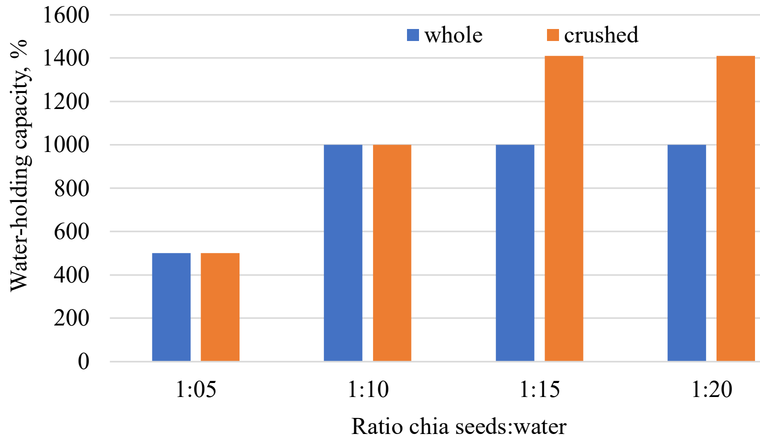

Fig. 4. Determining the indicator of water-holding capacity of whole and crushed chia seeds for different ratios of chia seeds:water (n=5, P≥0.95, σ=3.2...4.0 %)

It was established that for the ratio of chia seeds:water=1:5, the indicator of water retention capacity for whole seeds and for crushed seeds is at the same level and is equal to 500 %. For the ratio of chia seeds:water = 1:10, the value of the water-holding capacity indicator for both whole and crushed seeds increases equally – up to 1000 %. With a further increase in the proportion of water (to 1:15 and 1:20), the value of this indicator for whole seeds practically does not change, while for crushed seeds it increases by 2.8 times and is 1410 %.

5. 2. Results of investigating the effect of whole chia seeds on the quality of brewed whipped protein mass

According to study [26], it is recommended to use whole chia seeds for egg albumin-based batters.

Brewed whipped protein mass was obtained by whipping an aerated mixture of egg albumin and hydrated whole chia seeds with hot (t=65...67 °C) sugar-agar-molasses (or sugar-pectin-molasses) syrup (Fig. 1).

The quality of the brewed whipped protein masses was assessed by indicators of foaming coefficient and density (Fig. 5, 6).

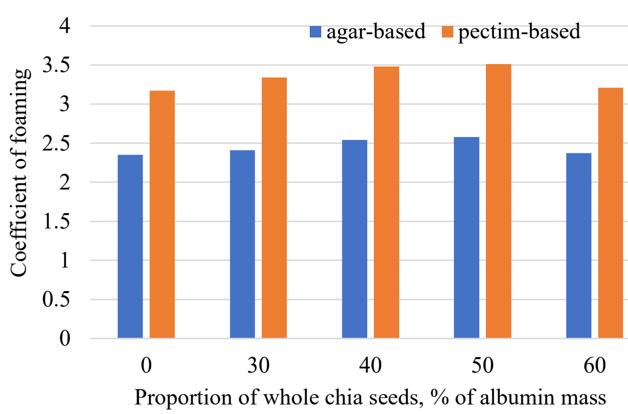

Fig. 5. Influence of chia seeds on the coefficient of foaming of brewed whipped protein mass made on different gelatinizers (n=4, σ=3.0...3.9 %)

It was established that the introduction of chia seeds helps improve the foaming of protein masses during whipping. The coefficient of foaming of samples with a 50 % additive content compared to the control increases by 9.8 % and 10.7, depending on the type of gelling agent used (on agar and pectin, respectively). At the same time, the obtained masses are characterized by a lower density than that of the control samples – by 7.3 and 9.5 %, respectively.

With the introduction of chia seeds in the amount of 60 % of the mass of egg albumin, the quality indicators of the brewed whipped mass are slightly worse compared to the sample with 50 % of the additive. The value of the foaming coefficient decreases by 8.1 and 8.5 %, the density increases by 6.0 and 9.8 %, respectively.

In accordance with the given task, regarding the improvement of the structural and mechanical properties of whipping candy masses, in further studies whipped brewed protein mass was used with the addition of whole chia seeds in the amount of 50 % of the mass of dry egg albumin.

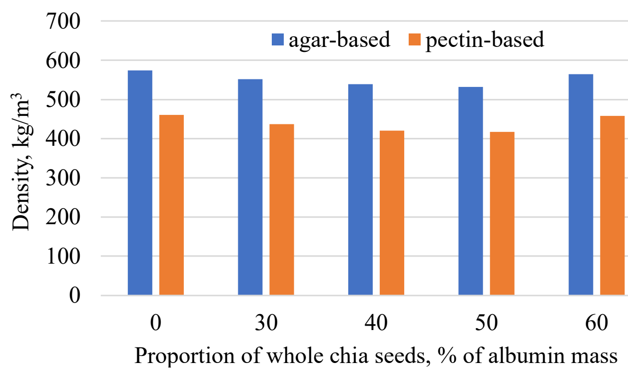

Fig. 6. Effect of chia seeds on the density of brewed whipped protein mass made on different gelatinizers (n=4, σ=3.3...4.1 %)

5. 3. Results of investigating the influence of chia seeds on the quality of whipped candies

Whipped candies were made in the manner shown in Fig. 3. In this case, whole chia seeds were introduced at the stage of obtaining the brewed whipped protein mass (Fig. 1) in the amount of 50 % of the mass of dry egg albumin. Crushed chia seeds were added during the preparation of milk-fat mass in the amount of 30, 40, 50, and 60 % of the mass of fat (Fig. 2). The quality of candy masses before structuring (unstructured) and after structuring (finished candies) was evaluated.

The structural and mechanical properties of unstructured candy masses were evaluated based on their viscosity. The temperature of the masses during the measurements was 55...60 °C, which corresponds to the temperature of their formation according to the technological scheme. The arithmetic mean results of determining the viscosity index are shown in Fig. 7 (n=5, σ=3.8...4.2 %).

It was established that in samples with the addition of only 50 % of whole chia seeds, the viscosity of the masses is slightly reduced compared to the control samples. In particular, for masses on agar – by 5.5 %, for masses on pectin – by 5.3 %. During the additional addition of crushed chia seeds to candy masses, the value of this indicator increases. Thus, in samples on agar and pectin with the addition of 50 % whole and 60 % crushed chia seeds, the increase in viscosity relative to the controls is 7.6 and 7.3 %, respectively.

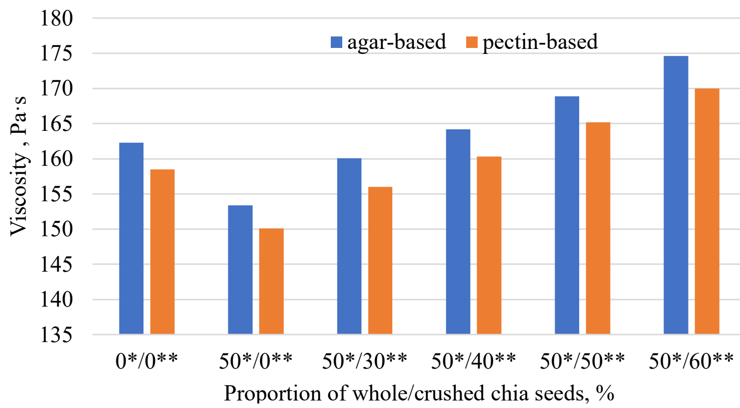

Fig. 7. Effect of chia seeds on the viscosity of unstructured candy masses (t=55…60 °C)

The quality of structured candy masses (ready-made candies) was assessed by the duration of their structure formation, structural characteristics (shrinkage, adhesion, strength, density) and organoleptic indicators.

A reduction in the duration of structure formation of candy masses with the introduction of chia seeds is noted (Fig. 8, n=5, σ=4.1…4.4 %).

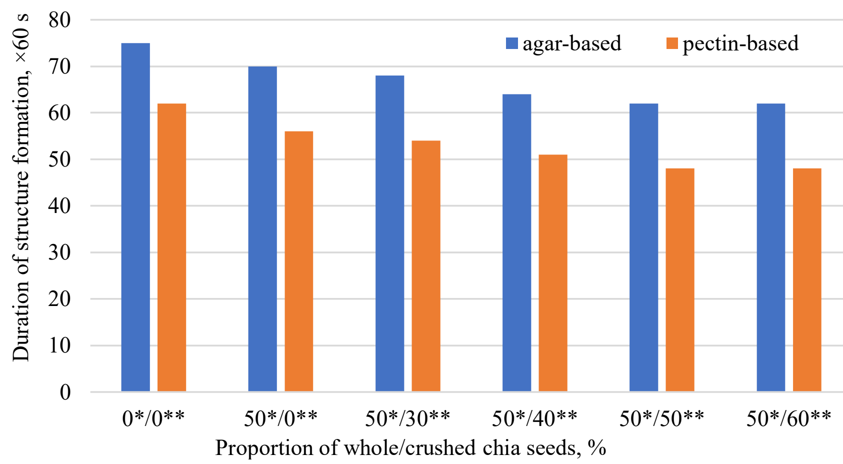

Fig. 8. Effect of chia seeds on the duration of structure formation of candy masses

The maximum decrease in the duration of structure formation is characteristic of samples with 50 % whole and 50 % crushed seeds – 14 and 16 min less compared to control samples on agar and pectin, respectively, that is, by 18.7 and 25.8 %. With an increase in the content of crushed chia seeds to 60 %, the duration of structure formation of the samples remains at the same level.

Shrinkage of cream-whipped candy masses characterizes the degree of reduction in their volume in the process of structure formation. The results of determining this indicator are shown in Fig. 9 (n=4, σ=4.0…4.3 %).

The rate of shrinkage of whipped candy masses decreases with the introduction of chia seeds. In samples containing only whole seeds, the value of this indicator, compared to the control, decreases by 7.3 and 5.1 relative percentages, depending on the type of gelling agent (on agar and pectin, respectively). In masses with the addition of 50 % of whole and 30 % of crushed seeds, the degree of reduction of this indicator relative to the control is 17.1 and 15.4 relative percentages, respectively. At the maximum dosage of the additive (50 % whole and 60 % crushed), shrinkage is almost at the level of samples with 50 % whole and 50 % crushed seeds. Its value is less than in control samples by 34.1 and 30.8 % for masses on agar and pectin, respectively.

The results of determining the structural and mechanical properties of ready-made whipped candies are given in Table 3.

It was found that an increase in the dosage of chia caused an increase in the strength and adhesion of whipped candies. Thus, with the maximum studied addition of the additive, the strength of the products compared to the control increases by 13.8 and 17.0 %, and the adhesion index – by 11.9 and 14.4 % for candies on agar and pectin, respectively. These samples also have higher density values of 7.6 and 9.5 %. However, it is noted that with the dosage of whole/shredded seeds (50/0) %, the density of the products is slightly lower than that of the corresponding control samples – by 4.2 and 1.7 %. With the dosage of chia (50/30) %, the value of the density indicator begins to increase, almost reaching the values of the control samples – the difference from the controls is 1.7 and 0.9 %, which is within the relative error of the experiment. Candies on agar and pectin with the content of whole/crushed seeds (50/50) % exceed the control by 5.0 and 6.9 %.

An evaluation of the organoleptic properties of ready-made whipped candies was also carried out (Table 4).

It was noted that chia seeds have the same effect on the organoleptic characteristics of whipped candies, regardless of the type of gelling agent used. With an increase in the dosage of the additive, the color of the candies becomes darker, and the number of scattered whole and crushed seeds on the fracture visually increases. Samples with a content of whole/crushed seeds (50/50) % have a light, pleasant nutty flavor, and aroma, and are similar in porosity and richness to the corresponding control samples. Candies, which include (50/60) % whole/crushed seeds, have a gray color, taste and aroma lose nutty notes and are perceived organoleptically as not inherent to such products. The structure of such products is denser, with non-uniform porosity, and less magnificence compared to other samples.

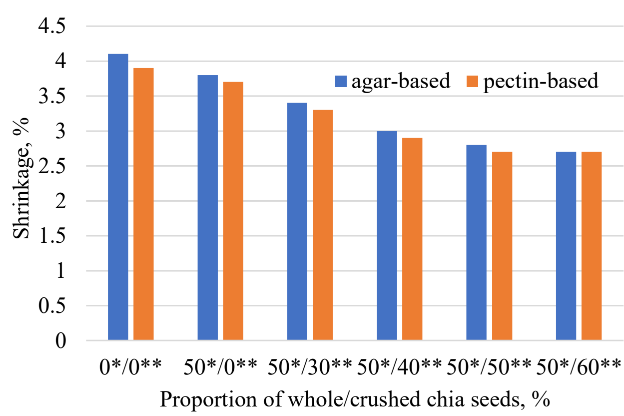

Fig. 9. Effect of chia seeds on the shrinkage of candy masses in the process of structure formation

Table 3

Structural and mechanical properties of the tested samples of whipped candies (n=5, σ=3.2...3.5 %)

Samples of sweets with the addition of whole*/crushed** chia seeds	Sample density, kg/m^3		Strength of samples, g		Sample adhesion, Pa	
	on agar	on pectin	on agar	on pectin	on agar	on pectin
0*/0**	595	580	592	687	277	264
50*/0**	570	565	595	701	280	269
50*/30**	585	580	616	728	288	281
50*/40**	615	600	634	754	294	288
50*/50**	625	620	648	768	302	294
50*/60**	640	635	674	804	310	302

*Note: * – % of dry protein mass; ** – % of fat mass.*

Table 4

Organoleptic characteristics of the investigated samples of whipped candies

<table>
<tr><th rowspan="2">Indicator</th><th colspan="6">Dosage of whole*/crushed** chia seeds (*% by weight of dry protein, **% by weight of fat)</th></tr>
<tr><th>0*/0**</th><th>50*/0**</th><th>50*/30**</th><th>50*/40**</th><th>50*/50**</th><th>50*/60**</th></tr>
<tr><td>Color</td><td>White</td><td>White, interspersed seeds are practically invisible</td><td>White with more noticeable gray patches of seeds</td><td colspan="2">It becomes darkened, the number of gray blotches increases with an increase in the dosage of seeds</td><td>Gray with a significant number of seeds</td></tr>
<tr><td rowspan="2">Structure, view at the break</td><td colspan="6">Denser for agar products, more tender and softer for pectin products</td></tr>
<tr><td>Finely porous, lush, porosity homogeneous</td><td colspan="2">The porosity becomes finer, the splendor of the mass increases, individual chia seeds are visible at the break</td><td colspan="2">In terms of porosity and splendor, similar to the control sample, individual chia seeds and specks of crushed seeds are visible at the break</td><td>Porosity becomes heterogeneous, splendor decreases, structure condenses</td></tr>
<tr><td rowspan="2">Taste</td><td colspan="6">Characteristic of this product, sweet</td></tr>
<tr><td colspan="2">No added</td><td colspan="2">With a slight nutty flavor</td><td>with a more pronounced nutty flavor</td><td>The taste loses its resemblance to a nut, feels like an extraneous</td></tr>
<tr><td rowspan="2">Smell</td><td colspan="6">Characteristic of whipped candies, pronounced</td></tr>
<tr><td colspan="3">No added</td><td colspan="2">A slight nutty aroma appears</td><td>More pronounced extraneous aroma</td></tr>
</table>

*Note: * – % of dry protein mass; ** – % of fat mass.*

In view of this, the recommended dosage of chia seeds during the production of whipped candies (on agar or on pectin) is 50 % of the mass of dry egg albumin (for whole) and 50 % of the mass of fat (for crushed).

The features of the nutrient composition of such candies made on agar and on pectin were analyzed in comparison with the corresponding control samples (Table 5).

It was found that in candies with chia seeds, compared to the corresponding control samples, the protein content increases – by 1.91 and 1.93 times for masses on agar and pectin, respectively. The fat content decreases (by 16.4 and 17.4 %), but their fatty acid composition improves – the content of polyunsaturated fatty acids in the developed products is higher by 18.2 and 18.7 %. The ratio of ω-3 and ω-6 fatty acids also changes. So, in samples without additive ω-3:ω-6=1:307, and in candies with additive – 1:1.09 for products on pectin, and 1:1.15 for products on agar. The content of non-starch polysaccharides (by 3.4 and 5.9 times) and polyphenolic compounds (by 23.6 and 23.2 times) is also significantly increased in the new products. From micronutrients, the content of potassium (by 32.5 and 30.1 %), calcium (by 2.4 and 2.3 times), magnesium (by 2.6 and 2.3 times), zinc (by 3.2 and 3.1 times), iron (in 1.7 and 1.6 times), vitamin C (in 30.0 and 29.0 times), vitamin E (in 8.0 and 5.3 times), PP (4.9 and 4.7 times).

Table 5

Analysis of changes in the content of the main nutrients in whipped candies on agar and pectin with the addition of chia seeds compared to control samples

Substance	Content in whipped candies, per 100 g			
	on pectin		on agar	
	control	with chia seeds	control	with chia seeds
1	2	3	4	5
Macronutrients, g				
Proteins	1.81	3.50	1.83	3.49
Fats	24.84	20.51	24.89	20.81
including PUFA:	3.95	4.67	3.95	4.69
linoleic (ω-6)	3.07	1.99	3.07	2.06
linolenic acid (ω-3)	0.01	1.83	0.01	1.79
Carbohydrates, g	57.40	59.60	57.67	59.84
including non-starch polysaccharides, g	0.97	3.29	0.46	2.72

Continuation of Table 5

1	2	3	4	5
Micronutrients, mg				
Potassium	103.16	136.70	108.2	140.75
Calcium	35.72	87.24	39.11	89.35
Magnesium	16.81	42.94	19.80	45.09
Zinc	0.19	0.61	0.20	0.63
Phosphorus	36.17	98.91	37.3	98.58
Iron	0.94	1.57	1.00	1.62
Vitamin C	0.01	0.30	0.01	0.29
Vitamin E	0.02	0.16	0.03	0.17
Vitamin PP	0.13	0.64	0.14	0.66
Polyphenols	0.56	13.20	0.56	12.98

Thus, the use of chia seeds in the technology of whipped candies improves their nutrient composition.

6. Discussion of results of investigating the use of chia seeds to improve the structural characteristics and nutrient composition of whipped candies

The chia seeds used in the research are characterized by a neutral aroma, a pleasant nutty taste, low humidity, and a slightly acidic environment (Table 1). Grinding seeds on the proposed equipment makes it possible to obtain a powder-like mass, which by the degree of dispersion belongs to coarsely dispersed systems (the average particle size is about 154 microns), but at the same time it has a high degree of uniformity (it contains 85 % of particles with a size of 110...200 microns and 66 % of particles with a size of 140...200 μm) (Table 2). Due to the grinding of chia seeds, the area of the active surface increases and the availability of functional groups improves. As a result, crushed chia seeds have a better ability to retain water compared to whole ones (Fig. 4). But this is typical for systems in which the ratio of chia seeds:water=1:15 and 1:20. That is, for the ratio of crushed chia seeds:water=1:5 and 1:10, there is not enough moisture in the system for its complete hydration. Thus, the sample of chia seeds used in the research, in its whole form, can retain moisture as much as 10 times in relation to its weight, and the crushed sample – in a multiple of 14.1 times. The obtained results correlate with the results of other researchers, according to which chia seeds can retain water in the amount of 7...27 units in relation to their weight, while forming a viscous gel [7, 8].

The resulting gel has good foaming properties [12] and has a positive effect on the stability of whipped masses based on egg albumin [26], as well as other polysaccharides of a similar type [30]. This explains the effect of improving the foaming of protein masses for candies during their whipping with hot syrup with gelling agent (Fig. 5), and, as a result, reducing their density (Fig. 6). The decrease in foaming coefficient in samples with 60 % replacement of albumin with chia seeds can be explained by two factors. On the one hand, the total amount of protein, which is the main foaming agent, decreases in the system. Mucilage substances of chia seeds only enhance its effect due to the formation of albumin-anionic polysaccharide complexes. Anionic polysaccharides are the components of chia mucoid substances – the remains of xylose, glucose, and galacturonic acid. On the other hand, it can be assumed that there is weighting of the mass due to the high density of chia seeds (1.069 g/cm^3 [7]), which also causes an increase in the density of such a sample (Fig. 6).

The obtained data correlate with the results of studies on the viscosity of unstructured whipped candy masses, in which the brewed whipped protein mass is combined with milk and fat. Thus, the sample with the addition of 50 % of whole chia seeds due to better aeration has a lower viscosity value compared to the control unstructured candy mass (Fig. 7). In the samples to which crushed chia seeds are added together with the milk-fat mass, the viscosity index gradually increases. This may be due, firstly, to a higher density of the additive. Secondly, crushed seeds are introduced at the stage of preparation of the milk-fat mass, the moisture content of which is insignificant (the moisture content of condensed milk is 26 %, margarine is 18 %). As a result, crushed chia seeds, whose moisture retention capacity is 1350 % (Fig. 4), do not have enough moisture for complete hydration. Therefore, when combined with brewed whipped protein mass, it begins to absorb its liquid phase, which causes an increase in viscosity. The samples of unstructured candy masses with the maximum content of chia seeds (50 % whole and 60 % crushed) in terms of the value of the viscosity index exceed the control by only 7.6 and 7.3 % (depending on the gelling agent) and are easily formed by smearing, as in the control technologies.

Due to higher viscosity, the duration of structure formation of candy masses with an additive is shortened (Fig. 8). In addition, such masses in the process of structure formation give less shrinkage (Fig. 9). This can be explained by the fact that chia seeds not only have a positive effect on the process of egg white foaming but also improve the stability of whipped masses based on it [26]. Also, the higher viscosity of unstructured masses with an additive leads to an increase in the strength of the studied samples after structuring (Table 3) due to an increase in the viscosity of the solutions inside the structural framework formed by agar and pectin.

The increase in the adhesion index of ready candies (Table 3) can be explained as follows. As a result of the additive's positive effect on foaming processes, more air cells of high dispersion are formed during mass whipping. At the same time, the total specific contact surface increases, ensuring more complete contact of the candy masses with the contacting surfaces. Increasing the adhesion of candies will improve their adhesion to the glaze during glazing and reduce the risks of its separation during storage of finished products.

An important indicator characterizing the structural properties of whipped candies is their density. The decrease in the density of products (Table 3) with small dosages of whole/crushed seeds ((50/0) % and (50/30) %) is due to their better aeration due to the foaming properties of chia. With an increase in the dosage of the additive, the candy density indicator begins to increase. However, according to the organoleptic characteristics (Table 4), the samples with the addition of whole/crushed seeds (50/40) % and (50/50) % in terms of porosity and richness are similar to the corresponding control samples. That is, for them, the increase in density is caused not by the deterioration of porosity but by an increase in the mass fraction of the denser component – whole and crushed seeds. The real deterioration of porosity and compaction of the structure is characteristic of samples with the maximum investigated additive content, regardless of the type of gelling agent. This can be explained by the sedimentation of the seed and its high water-holding capacity. Probably, in such systems, the amount of crushed seeds becomes critical, it "draws" moisture from the protein films surrounding the air cells. As a result, the cells decrease in size, which causes the structure of the products to be compacted.

That is, it is possible to conclude about the expediency of adding whole/crushed chia seeds in the amount of up to (50/50) % of the weight of dry albumin/fat to the recipes of whipped candies on agar and pectin. Such dosages have a positive effect on the structural characteristics and organoleptic properties of finished products.

In addition, such products are characterized by improved nutrient composition (Table 5). The content of proteins and non-starch polysaccharides increases. The balance of fats is also improved by changing the ratio of ω-3:ω-6 fatty acids from 1:307 in the control samples to 1:1.09 and 1:1.15 for products on pectin and agar, respectively. The optimal ratio of these acids from the perspective of a balanced diet should be in the range of 1:(4...10) [31]. However, modern diets are overloaded with ω-6 fatty acids. Therefore, such a change in the ω-3:ω-6 ratio in new products is positive. The content of micronutrients: polyphenolic compounds, minerals (potassium, calcium, magnesium, zinc, and iron) and vitamins (C, E, PP) is also significantly increased in the developed candies.

Thus, there are reasons to believe that the use of whole and crushed chia seeds in the technology of whipped candies makes it possible to improve their structural characteristics and nutrient composition. This will ensure the competitiveness of new products in the modern market.

The peculiarity of the proposed technology of whipped candies and the difference from existing ones is the use during its implementation of whole and crushed chia seeds in the amount of 50 % of the dry protein mass and 50 % of the fat mass, respectively. This makes it possible to intensify the production process, improve its structural and mechanical, organoleptic characteristics, and fortify it with substances useful for the human body.

The given data are limited exclusively to the technology of whipped candies on agar and on pectin since the application of the proposed technological solutions for other technologies requires additional research.

The disadvantage of the given data is that the work was carried out with specific types of gelatinizers. The choice of other gelling agents (carrageenan, modified starch) can cause changes in the properties of semi-finished and finished candies. Also, the quality assessment of new products for storage was not carried out.

Therefore, the further development of research involves the study of changes in the main characteristics of whipped candies with the addition of chia seeds during storage and the study of their main characteristics using other types of gelling agents.

7. Conclusions

1. It has been established that the chia seeds used in the research are characterized by low moisture content and a slightly acidic environment. Crushed seeds have an average particle size of about 154 μm and a high degree of uniformity (contains 85 % of particles with a size of 110...200 μm). Crushed chia seeds have a better ability to retain water compared to whole. The studied sample of chia seeds, in its whole form, can retain moisture as much as possible in a multiple of 10 times in relation to its weight, and a sample of crushed – in a multiple of 14.1 times.

2. It has been established that the introduction of whole chia seeds in the amount of up to 50 % of the mass of dry egg albumin, inclusive, contributes to the improvement of foaming of protein masses during whipping – by 9.8 % and 10.7 % for masses on agar and pectin compared to the corresponding control samples. Their density also decreases – by 7.3 and 9.5 %, respectively. Increasing the dosage of chia seeds to 60 % causes a deterioration of these indicators. In view of this, it is recommended to limit the dosage of whole chia seeds to the brewed whipped protein mass at the level of 50 % of the mass of dry albumin.

3. It has been noted that the introduction of whole/crushed chia seeds in the amount of (50/40) %, (50/50) % and (50/60) % of the mass of dry albumin/fat increased the viscosity of unstructured candy masses (with a temperature of 55...60 °C) increases somewhat. Due to this, the duration of their structure formation is reduced, and the rate of mass shrinkage decreases. Whipped candies obtained on the basis of such masses, compared to control samples, are characterized by higher values of adhesion, strength, and density indicators. With organoleptic characteristics, the samples with the addition of whole/crushed seeds (50/40) % and (50/50) % are similar to the corresponding control samples in terms of porosity and richness. Real deterioration of porosity and compaction of the structure is characteristic of samples with the content of whole/crushed seeds (50/60) %. That is, the introduction of chia seeds in the amount of up to 50 % of the mass of dry egg albumin (for whole) and 50 % of the mass of fat (for chopped) to the recipes of whipped candies on agar and on pectin has a positive effect on their structural characteristics and organoleptic properties. Such products are characterized by improved nutrient composition.

In particular, the content of proteins and non-starch polysaccharides increases. The balance of fats is also improved by changing the ratio of ω-3:ω-6 fatty acids, and the content of micronutrients: polyphenolic compounds, minerals (potassium, calcium, magnesium, zinc, and iron), and vitamins (C, E, PP) is significantly increased. Technological proposals developed in this way make it possible to obtain whipped candies with improved structural characteristics, attractive organoleptic properties, and a higher content of nutrients useful for the human body.

Conflicts of interest

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

Funding

The work was carried out within the state budget topic No. 3-24-25 BO "Development of hardware-technological solutions for the production of multipurpose functional food products for people living under extreme conditions."

Data availability

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

Use of artificial intelligence

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

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