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DETERMINING THE INFLUENCE OF PLANT-BASED PROTEINS ON THE CHARACTERISTICS OF DAIRY ICE CREAM

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This paper investigates the functional and technological properties of proteins in the composition of dairy ice cream. The object of the research was the technology of ice cream with plant-based proteins. The problem to be solved was the improvement of physical-chemical and rheological characteristics of mixtures and ice cream with a low fat content by using moisture-binding structuring proteins of plant origin.

It was established that pea protein concentrate has the highest foaming properties. Oat protein concentrate shows a moderate ability to form and stabilize foams, while soy protein isolate does not reveal this function at all. The presence of plant-based proteins in all ice cream mixtures increases their nominal viscosity, but the highest thixotropy is observed for the concentrate of pea (56.5–61.0 %) and oat (54.8–57.2 %) proteins. They form food systems with a pronounced coagulation structure, which are capable of self-repair of bonds during the maturation of mixtures for 8 hours. Soy protein isolate reduces the thixotropic ability of ice cream mixtures, which limits the expediency of its use. The defined physical-chemical indicators of ice cream make it possible to justify the rational content of proteins in the composition of ice cream, which is 1–2 % for pea protein concentrate and 1 % for oat protein concentrate.

Data on the rheological behavior of ice cream mixtures do not always coincide with previously established patterns, which is due to the difference in chemical composition between the studied food systems, as well as methods of their preparation and use.

The results of this work could be used in the technology of low-fat ice cream, as well as in compositions for new types of ice cream enriched with protein

Keywords: oat protein, soy isolate, pea protein, low-fat ice cream

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1. Introduction

The market of ice cream and frozen desserts is characterized by constant development taking into account the trends and requirements from modern consumers. The popularity of commercial and semi-industrial types of ice cream, such as low-fat, low-calorie, vegan, sour-milk, etc., is growing [1–3]. However, the use of innovative ingredients and a significant reduction in fat content do not always positively correlate with the quality of the finished product of the new formulation. Traditional types of ice cream contain 10–16 % fat, which enables formation of a creamy texture of the product, due to the binding of free water and contributes to the formation of a rich creamy taste [4, 5]. A decrease in the mass fraction of fat in ice cream leads to an increase in water content and a corresponding increase in the melting rate due to a decrease in the stability of air bubbles, which certainly affects the perception of the product by consumers [6, 7]. Protein additives in ice cream may not only increase its biological value but also perform certain technological functions. It is known that proteins have pronounced functional and technological properties, such as increasing whipping, structuring of ice cream mixtures during ripening, active binding of free water and prevention of structural and mechanical defects [8, 9]. One of the most researched and commercially approved proteins of animal origin are, in particular, concentrates and isolates of whey proteins [10]. Proteins of plant-based origin cause no less interest in the food industry but research on their use in low-fat types of ice cream is extremely limited. That is why the scientific substantiation of the recipe composition of low-fat ice cream with plant-based proteins and the study of their influence on the rheological and physical-chemical characteristics of ice cream is an actual area of applied scientific work.

2. Literature review and problem statement

The most common in the food industry are soy protein supplements, which is due to their affordability and proven functional and technological properties [11]. The main properties of soy proteins in ice cream technology include interphase (water-retaining, fat-binding, and emulsifying properties), technological (structuring properties), organoleptic (improvement of taste, texture), and food (increase in energy and biological value) [12, 13].

In [14] it was reported that soy protein concentrate in the amount of 5 % effectively emulsifies vegetable fat in soft ice cream and improves its structural and mechanical characteristics. The results of another study [15] indicate that soy protein isolate (2–4 %) in milk-based ice cream mixes increases viscosity and has a positive effect on the organoleptic properties of the finished product. To improve the dispersion of fat in ice cream mixes, from 40 to 80 % of dry whole milk was replaced with soy protein isolate [16], which increased the viscosity of the mixes with subsequent formation of a dense ice cream structure. However, replacing dry milk with soy protein isolate reduced ice cream churning by 60–80 %. The reason for this may be an excessive increase in the viscosity of the mixtures, which made it difficult to saturate them with air. An option to overcome the relevant difficulties can be the substantiation of the rational content of soy proteins in the composition of ice cream. This is the approach used in work [17], in which soy protein in strawberry ice cream in the amount of 1.5–3.0 % is positively correlated with the index of whipping and resistance to melting. But the issues remain unresolved, related to the fact that most studies with soy proteins were conducted as a fat replacer in ice cream with a mass fraction of 5–16 % fat, but there is very little data on its use in low-fat or non-fat types of ice cream. This is probably due to the fact that traditional types of ice cream contain a fairly high proportion of fat while the popularity of low-fat ice cream production began to increase during the last decade.

For the production of ice cream, pea protein concentrate, obtained from the seeds of *Pisum sativum* pea, is also promising. Pea protein has a broad amino acid profile, including more arginine than soy or egg protein, large amounts of lysine and glutamine, and BCAAs only 2 % less than casein [18]. It was shown [19] that 6–12 % pea protein concentrate provides the most effective interaction between ice cream components for the formation of proper organoleptic and physicochemical characteristics, in particular, it improves the texture and stabilizes the structure. However, exceeding the rational content of pea concentrate leads to a decrease in whipping. The reason for this is the formation of a too hard texture of the product. A possible solution to this problem may be the search for a rational mass fraction of the ingredient or its combination with polysaccharides. One of these approaches is shown in [20], in which the combination of 2–4 % pea protein concentrate with inulin increases the whipping ability of ice cream from 16 % to 36.2–38.48 %. In another work [21], it was proven that microparticles of pea protein concentrate compact the structure of ice cream, increase stickiness, and enhance the sensation of creamy taste. Scientists drew attention [22] to the increased ability of pea proteins to foam and gel, stabilize foam and dissolve in water, which is promising for their use in the composition of ice cream, in particular low-fat. All this confirms the prospect of studying the influence of pea proteins on the characteristics of ice cream.

Oat protein ingredients are another relevant ingredient for ice cream production. From the point of view of nutritional value, proteins isolated from oats have high digestibility (90.3–94.2 %), biological value (74.5–79.6 %), as well as protein utilization rate (69.1–72, 4 %) [23]. In the food industry, oat proteins can be used as effective thickeners, emulsifiers, texture modifiers, and stabilizers due to their pronounced functional properties, such as foaming, water-binding, and fat-forming abilities [24, 25]. However, no determination of the effect of oat proteins in ice cream was found. A potential reason for this may be that oat protein concentrates have only recently become commercially available.

Therefore, the use of plant-based proteins in the composition of ice cream has been investigated without a proper analytical comparison of their functional and technological properties, including in a product with a low fat content and an increased free water content.

All this gives reason to assert that it is appropriate to conduct a study aimed at analyzing the impact of plant-based proteins on quality indicators and separate technological operations in the production of dairy ice cream.

3. The aim and objectives of the study

The purpose of our work is to determine the effect of proteins of plant origin on the physical and chemical characteristics of dairy ice cream in the production process. This will make it possible to justify the rational amounts of plant-based proteins in the composition of ice cream, which enable formation of proper rheological and physical-chemical indicators of the product.

To fulfill the set goal, the following tasks of scientific research were formulated:

– to investigate the functional and technological properties of plant-based protein ingredients;

– to investigate the influence of protein ingredients on the rheological behavior of ice cream mixtures;

– to determine the main physical-chemical indicators and justify the appropriate amounts of proteins in the composition of dairy ice cream.

4. The study materials and methods

4. 1. Materials and equipment used in the experiment

The object of our research is the technology of dairy ice cream with plant-based proteins.

The main hypothesis of the study assumes that plant-based proteins (soy protein isolate, pea protein concentrate, oat protein concentrate), due to their functional and technological properties, are able to improve the rheological characteristics of ice cream mixtures and the physicochemical parameters of the finished product.

Soy protein isolate 90 % (ISOPRO 900EM-UPI, China), pea protein concentrate 85 % (TM NOSOROG, Ukraine), oat protein concentrate 80 % (Xi'an Salis Biological Co. Ltd, China) were selected for use in ice cream.

The content of the stabilization system Cremodan® SI 320 (Danisco, Denmark) in the ice cream recipes was 0.5 % in accordance with the manufacturer's recommendations for ice cream with a reduced fat content (up to 5 %).

Pasteurized milk (fat content – 3.2 %), white sugar, skimmed milk powder, and drinking water were used as basic ingredients for ice cream production (Table 1).

Mixtures of dairy ice cream were obtained by mixing loose ingredients (Table 1) and then dissolving them in a mixture of liquids, which was preheated to a temperature of 40–45 °C. To remove possible residues of undissolved particles of protein additives, the mixture was filtered through a filter with a pore diameter of up to 1 mm before pasteurization.

Table 1

Recipes for dairy ice cream enriched with plant-based proteins

Ingredients	Weight of components, kg, per 1000 kg (excluding losses)						
	Control	1 % SPI[1]	2 % SPI	1 % PPC[2]	2 % PPC	1 % OPC[3]	2 % OPC
Milk, pasteurized	625.0	625.0	625.0	625.0	625.0	625.0	625.0
White sugar	150.0	150.0	150.0	150.0	150.0	150.0	150.0
Dry skimmed milk	46.3	46.3	46.3	46.3	46.3	46.3	46.3
Stabilization system	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Soy protein isolate	–	10.0	20.0	–	–	–	–
Pea protein concentrate	–	–	–	10.0	20.0	–	–
Oat protein concentrate	–	–	–	–	–	10.0	20.0
Water, drinking	173.7	163.7	153.7	163.7	153.7	163.7	153.7
Total	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0

Note: [1] – soy protein isolate, [2] – pea protein concentrate, [3] – oat protein concentrate

Pasteurization was carried out at a temperature of 84±2 °C with a holding time of 120 seconds. The mixtures were homogenized under a pressure of 12±1 MPa using a laboratory homogenizer-disperser model 15M-8TA "Lab Homogenizer & Sub-Micron Disperser" (Gaulin Corporation, Boston, MA, USA). The homogenized mixtures were cooled to a temperature of 2 °C and subjected to ripening before freezing for 8–24 h. Experimental samples of ice cream were obtained using a semi-industrial batch freezer FPM-3.5/380-50 "Elbrus-400" (VAT "ROSS", Kharkiv, Ukraine). The temperature of the mixtures before freezing was 4±2 °C. The temperature of soft ice cream at the exit from the freezer was −5.0±0.5 °C. Freezing of mixtures was carried out in two stages:

– at the first stage, the mixture was frozen in a cooling cylinder (volume – 7 l) to a temperature of −1 °C at a rotation frequency of the scraper stirrer of 4.5 s^{-1} for 120 s;

– at the second stage, the mixture was frozen at a rotation frequency of 9 s^{-1} for 180 s to a temperature of −5.0±0.5 °C.

The ice cream samples were additionally hardened and stored in a freezer by "Caravell" A/S (Løgstrup, Denmark) at a temperature of −18±1 °C.

4. 2. Methods for investigating mixtures and ice cream

The water-holding capacity of proteins was determined by the centrifugation method [26]. Samples of protein additives (10 g) were placed in glass tubes and heated for 60 min in a water bath (90 °C). After heating, the samples were removed, cooled to room temperature, wrapped in cotton gauze, and centrifuged in polycarbonate tubes (containing absorbent fabric) for 15 minutes at a rotation frequency of 4000 rpm at 4 °C. The gauze was removed, and the weight of the samples was recorded. The following formula was used to calculate the water-holding capacity (*WHC*, %):

$$WHC=1-T/M\times100=1-B-A/M\times100, \tag{1}$$

where T is the total liquid loss during heating and centrifugation;

B – mass of the sample before heating;

A is the mass of the sample after heating and centrifugation;

M is the total water content in the sample.

The foaminess of aqueous protein solutions was measured after they were cooled to a temperature of 2–6 °C and whipped for 5, 10, and 15 min with 5-minute breaks according to a modified method [27]. The foaming rate was calculated as the ratio of the volume of the whipped mixture to its initial volume, expressed as a percentage.

The Foam stability of protein mixtures was determined according to the modified procedure by Philips L., according to which a container with a hole in the bottom was used for foam to drain after whipping [27]. The time during which 50 % of the initial volume of the mixture used for whipping is formed as a result of foam destruction was taken as an indicator of foam stability.

The mass fraction of dry matter in ice cream samples was determined by the arbitration method [28], the protein content by the Kjeldahl method, the fat content by the modified Gerber method [29], the acidity was measured by inserting the electrodes of a potentiometric analyzer into the ice cream mixture at a temperature of 20 °C.

The relative density (density relative to water) of ice cream mixtures was determined by the pycnometric method [30]. The pycnometer was first weighed empty, then filled with distilled water, and then with ice cream mixture at 25 °C, recording the weight each time.

The relative density (SG, kg/cm^3) was calculated according to the following formula:

$$SG=(m_1-m_2)/(m_3-m_2), \tag{2}$$

where m_1 is the mass of the pycnometer with the ice cream mixture;

m_2 is the mass of the empty pycnometer;

m_3 is the mass of the pycnometer with distilled water.

Viscosity characteristics were determined on a rotary viscometer with a "cylinder-cylinder" measuring system by taking deformation kinetics curves. The research was carried out at a temperature of 20 °C. Shear stress τ (Pa) was measured at twelve values of the shear rate gradient D in the range from 3 to 1312.2 s^{-1} during forward and reverse motion. The maximum effective viscosity of the practically undamaged structure (γ=3 s^{-1}), the minimum effective viscosity of the marginally destroyed structure (γ=1312.2 s^{-1}), and the effective viscosity of the restored structure (γ=3 s^{-1}) were recorded. The degree of restoration of the structure of ice cream mixtures (thixotropic ability) was determined as a percentage by the difference in the values of the effective viscosity of the practically intact structure at the beginning and at the end of the measurement at a shear rate gradient (γ=3 s^{-1}) [31].

Water activity in whey concentrates and ice cream mixtures was determined on a water activity analyzer "HygroLab 2" (Rotronic, Switzerland) at a temperature of 20 °C in the measurement range of 0–1 Aw (0–100 % rh) [32].

The whipping ability of ice cream was determined by the weight method based on the difference in the mass of samples of the same volume of mixture and ice cream, expressed as a percentage [33].

Resistance to melting (the time of the first drop flowing out and the time of accumulation of 10 cm^3 of melted ice cream) was determined at an ambient temperature of 22 °C [26]. Ice cream samples were placed on a special grid (d=95 mm, holes 5×5 mm, wire thickness 0.5 mm) and the time until the ice cream completely melted was recorded [34].

Statistical analysis was performed using the Statistika 10 software. Data were expressed as the mean value with standard deviation of triplicate measurements. Differences were considered reliable at validity α=0.95. Construction of flow rheograms of ice cream mixtures was carried out in the Microsoft Excel 2016 environment. To ensure the reliability of results, the experiment was carried out three times.

5. Results of investigating milk mixtures and ice cream enriched with plant-based proteins

5. 1. Results of investigating the functional and technological properties of plant-based protein ingredients

At the first stage of the experiment, the properties of hydrated plant proteins and their solutions were investigated (Table 2). The water-holding capacity for all proteins is in the range of 357.4–543.8 %, which can be considered high enough when choosing technological additives for use in food products. The greatest increase in this indicator is observed for soy protein isolate and pea protein concentrate. The correlation between the water-holding capacity of proteins and relative density was also monitored, which confirms their ability to retain part of the free water in food systems.

Table 2

Functional and technological properties of plant proteins and their solutions (p≤0,05, n=3)

Indicator		Hydrated vegetable proteins and their colloidal solutions					
Water-holding capacity, %		543.8±5.2		511.6±3.8		357.4±1.4	
Mass fraction and type of protein		1 % SPI[1]	2 % SPI	1 % PPC[2]	2 % PPC	1 % OPC[3]	2 % OPC
Foam whipping, %	5	113.5±2.5	114.0±1.1	140.1±0.8	144.2±1.6	122.4±1.7	125.3±0.5
	10	117.4±1.8	120.9±1.5	148.5±4.6	160.6±3.8	126.3±4.4	129.0±2.0
	15	114.3±3.4	115.7±2.9	147.2±3.7	158.1±2.9	125.7±3.2	128.6±3.4
Foam stability, min	5	10.5±0.5	10.9±0.3	14.8±0.5	16.2±0.8	11.7±0.1	13.8±0.2
	10	11.4±0.1	11.8±0.3	15.2±0.6	16.5±0.5	12.5±0.6	13.9±0.5
	15	11.5±0.3	11.7±0.1	15.0±0.2	17.1±0.4	12.3±0.1	14.2±0.3
Relative density, kg/cm^3		1017.2±0.8	1019.5±1.0	1013.4±0.1	1013.9±0.6	1008.5±0.5	1010.8±0.7

Note: [1] – 1 % soy protein isolate, [2] – 1 % pea protein concentrate, [3] – 1 % oat protein concentrate, 5, 10, 15 – duration of whipping the mixture

As evidenced by the data in Table 2, there is an ability of pea protein concentrate (1–2 %) to form and stabilize foams. Oat protein concentrate (1–2 %) shows a moderate processing effect, while soy protein isolate shows the lowest level of foaming and foam stability.

5. 2. Results of investigating the influence of protein ingredients on the rheological behavior of ice cream mixtures

The use of protein ingredients makes it possible to increase the protein content in ice cream from 3.62 % to 4.41–5.40 %, which is an additional advantage, taking into account the increasing interest of consumers in products with an increased protein content (Table 3).

Table 3

Chemical composition of dairy ice cream enriched with plant-based proteins (p≤0.05, n=3)

Indicator	Sample						
	Control	1 % SPI[1]	2 % SPI	1 % PPC[2]	2 % PPC	1 % OPC[3]	2 % OPC
Solids, %	27.41±0.22	28.33±0.12	29.28±0.14	28.41±0.39	29.34±0.10	28.38±0.16	29.47±0.22
MSNF, %	8.06±0.17	8.05±0.3	8.01±0.21	8.01±0.15	8.05±0.11	8.03±0.21	8.01±0.12
Fat, %	2.01±0.05	2.00±0.03	2.03±0.01	2.00±0.02	2.08±0.01	1.99±0.05	2.02±0.01
Protein, %	3.62±0.04	4.51±0.03	5.40±0.08	4.52±0.07	5.37±0.01	4.41±0.04	5.12±0.02

Note: [1] – soy protein isolate, [2] – pea protein concentrate, [3] – oat protein concentrate

In order to study the influence of plant-based proteins on the viscous characteristics of ice cream mixtures and to establish a rational duration of ripening, it was decided to investigate their rheological characteristics of behavior (Table 4).

The presence of plant-based proteins in the mixtures leads to an increase in nominal viscosity in all samples, however, their effect on the restoration of the structure is quite different. Pea protein concentrate has the greatest effect on the degree of thixotropy of mixtures, increasing it from 50.7–51.9 % to 56.5–61.0 %. A slightly lower activity is demonstrated by oat protein concentrate, enabling the restoration of the structure at the level of 54.8–57.2 %. Whey protein isolate, despite increasing the viscosity of the systems, reduces the thixotropic ability of ice cream mixtures in all cases, except for the use of its mass fraction of 2 % for the maximum duration of ripening (24 h).

The use of pea and oat protein concentrates in the composition of ice cream mixes makes it possible to shorten the duration of their ripening process to 8 hours, which enables the formation of rheological characteristics at a higher level than in the control sample with a ripening duration of 24 hours.

Taking into account the obtained data, the rational duration of maturation for ice cream mixtures is 8 h in the case of using pea and oat protein concentrates and 16 h for soy protein isolate.

In order to gain a deeper understanding of the effect of plant-based protein additives on the structuring of low-fat ice cream mixtures, flow rheograms were analyzed. Fig. 1 shows examples of the control mixture and test samples, which make it possible to reduce the duration of ripening to 8 hours while maintaining proper rheological indicators.

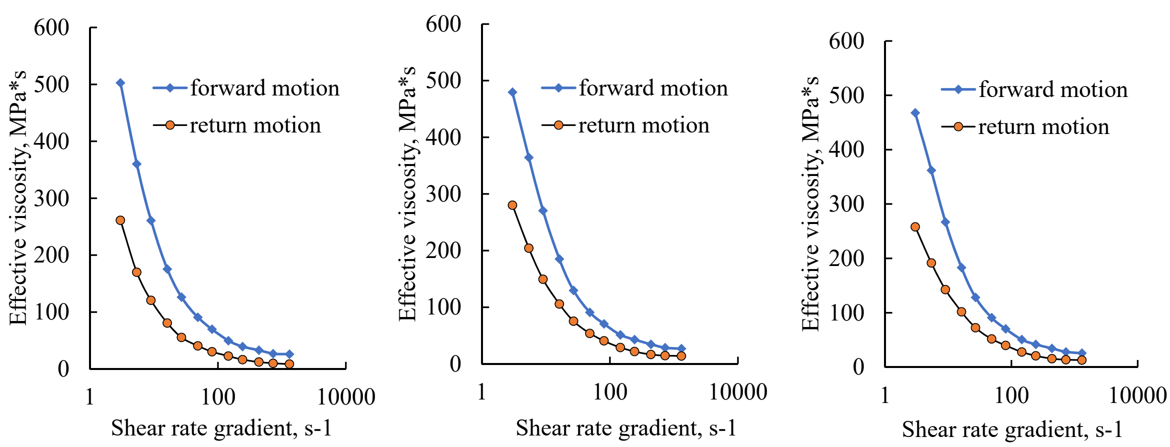
The results of our analysis of flow rheograms of mixtures with plant-based proteins (Fig. 1) indicate their ability to self-recover after the destruction of bonds. That is, these food systems can be classified as having a coagulation structure with pronounced thixotropic ability.

Table 4

Rheological characteristics of ice cream mixtures for different ripening durations ($p \leq 0.05$, $n=3$)

Duration of ripening, hours	Effective viscosity (mPa×s) at variable shear rate gradient			Time of ultimate destruction of the structure ($\gamma=1312.2\ s^{-1}$), min	Degree of restoration of the structure, %
	$\gamma=3\ s^{-1}$ (forward motion)	$\gamma=1312.2\ s^{-1}$	$\gamma=3\ s^{-1}$ (return motion)		
Control					
8	432.8±10.2	24.9±1.0	219.5±7.7	5.0±0.1	50.7
16	469.6±8.9	25.8±1.1	242.4±5.3	5.1±0.2	51.6
24	502.7±15.4	26.1±1.3	261.0±11.2	5.3±0.1	51.9
1 % SPI					
8	473.2±10.5	21.2±1.0	237.6±9.8	4.6±0.2	50.2
16	501.7±9.2	21.5±0.8	254.4±11.3	4.8±0.1	50.6
24	515.3±12.6	21.6±1.0	263.7±12.0	4.8±0.1	51.2
2 % SPI					
8	489.7±14.3	21.3±0.5	246.3±9.4	4.7±0.1	50.3
16	518.2±11.8	21.0±1.0	263.9±10.6	4.9±0.1	50.9
24	535.1±12.5	21.8±0.9	279.2±10.2	5.0±0.1	52.2
1 % PPC					
8	468.8±11.5	26.1±1.3	265.1±11.6	5.8±0.1	56.5
16	490.1±15.6	26.4±1.1	278.3±10.4	6.0±0.1	56.8
24	509.0±13.9	26.5±0.8	296.9±9.1	6.1±0.2	58.3
2 % PPC					
8	479.6±11.9	26.8±0.9	280.2±13.7	6.0±0.2	58.2
16	503.5±13.4	26.9±1.2	298.8±10.2	6.2±0.2	59.3
24	515.9±10.6	27.0±1.0	319.4±8.1	6.5±0.3	61.9
1 % OPC					
8	456.7±12.2	25.2±1.2	250.5±10.0	5.5±0.1	54.8
16	481.3±10.7	25.3±0.6	264.9±6.7	5.6±0.1	55.0
24	505.2±11.0	25.3±1.0	285.6±10.9	5.7±0.1	56.5
2 % OPC					
8	467.8±7.8	25.6±1.0	258.0±10.1	5.5±0.1	55.1
16	495.5±12.9	25.7±1.1	276.8±10.5	5.7±0.2	55.9
24	510.1±12.3	26.0±1.1	291.7±12.6	5.9±0.1	57.2

Note: [1] – soy protein isolate, [2] – pea protein concentrate, [3] – oat protein concentrate



a *b* *c*

Fig. 1. Dependence of the effective viscosity of ice cream mixtures on the shear rate gradient: *a* – control; *b* – 2 % pea protein concentrate; *c* – 2 % oat protein concentrate

5. 3. Results of investigating the physical-chemical indicators and substantiating the expediency of the amounts of proteins in the composition of dairy ice cream

The activity of water for all samples is within the generally known limits, with an insignificant decrease in ice cream mixtures with plant-based proteins. This phenomenon is caused by an increase in the mass fraction of dry substances in the system and the corresponding binding of free water (Table 5).

As the mass fraction of proteins increases, the acidity of the product decreases, which is especially noticeable when using oat protein concentrate (2 %). It should be noted that there is no correlation between the relative density index of ice cream mixtures and the water-holding capacity of protein additives, as was the case with aqueous protein solutions. This phenomenon may be related to the fact that ice cream mixtures are multicomponent systems in which the influence of individual components on the complex of physicochemical indicators of the product is present.

Table 5

Physical-chemical indicators of experimental mixtures and ice cream (p≤0,05, n=3)

Sample		Indicator						
		Control	1 % SPI[1]	2 % SPI	1 % PPC[2]	2 % PPC	1 % OPC[3]	2 % OPC
Whipping ability, %		61.2±0.8	54.0±1.1	49.2±1.5	69.4±0.6	73.7±1.0	63.6±0.7	59.9±1.4
Resistance to melting, min	1	27.1±1.1	32.9±1.0	33.5±1.2	28.4±0.9	29.8±1.1	27.6±0.8	28,3±0,5
	14	28.6±0.6	35.7±0.9	36.4±0.4	30.2±1.4	31.0±0.9	29.1±1.0	29,8±1,1
	28	31.3±1.3	36.1±1.0	36.7±1.4	34.5±1.2	35.1±1.2	33.4±1.1	35,0±0,7
Acidity		6.81±0.01	6.74±0.02	6.69±0.01	6.79±0.05	6.70±0.01	6.68±0.04	6.59±0.02
Relative density, kg/cm^3		1101.1±1.5	1118.5±1.1	1119.6±0.5	1112.7±1.9	1116.2±2.4	1109.4±1.4	1111.0±1.9
Water activity, units		0.962±0.001	0.961±0.001	0.959±0.002	0.961±0.001	0.958±0.001	0.960±0.001	0.959±0.002

Note: [1] – soy protein isolate; [2] – pea protein concentrate, [3] – oat protein concentrate, 1, 14, 28 – duration of ice cream storage

The greatest increase in the whipping ability of ice cream, compared to the control ice cream, was observed in samples with 1–2 % pea protein concentrate. Oat protein concentrate provided a slight increase in whipping only at a minimum mass fraction (1 %), but its further increase leads to deterioration of air saturation of the mixture (Table 5). Soy protein isolate reduces the curdling of ice cream at any concentration (1–2 %).

A certain correlation is observed between the index of whipping and resistance to melting. The higher the degree of air saturation of the ice cream, the faster the melting speed. As the duration of ice cream storage increases, the resistance to melting increases, which is especially noticeable on day 28.

6. Discussion of results related to the properties of plant proteins and their influence on the characteristics of dairy ice cream

The foam-forming properties of proteins of plant origin have not been studied in detail (Table 2) because in scientific works the main attention is paid to the gel-forming ability of mixed protein compositions [35, 36]. It was previously reported [37] that all model solutions with soy protein isolates showed low foamability and stability. Such results may be related to the fact that soy proteins in the soluble fraction have limited protein mobility, as a result of which the formation of a complete interfacial film is not ensured [38]. On the contrary, pea and oat protein concentrates have a high ability to foam, which confirms their functional characteristics [39–41]. However, it should be noted that the interphase activity of these protein ingredients may also vary depending on the composition of the model systems, the technique of their preparation and processing.

Regarding the chemical composition of ice cream with plant-based proteins (Table 3), according to the mass fraction of dry substances, it can be classified as a low-fat product (mass fraction of fat – 2–5 %) but according to the mass fraction of MSNF, it can be categorized as a premium product (mass fraction of fat – 12–14 %) [42]. If we consider the protein content, then it increases from 3.62 % to 4.41–5.40 %, depending on the added protein ingredients, which is higher compared to classic low-fat analogs. This is explained by the additional enrichment of ice cream with protein isolates and concentrates. It was also reported [43] that ice cream has a high content of MSNF, of which 34–36 % is protein, which provides ice cream with its average mass fraction at the level of 2.5–4 %. According to the obtained data [44], the protein content is 36 % of the total content of MSNF, that is, 2.1–5.1 % for traditional types of ice cream and 0.1–4.4 % for amateur ice cream. Regardless of the chosen classification of the chemical composition of ice cream, the use of the maximum mass fraction of selected proteins (2 %) in the composition of dairy ice cream provides for its increased content.

The study of the influence of plant-based proteins on the rheological characteristics of ice cream mixtures (Table 4) indicates the ability of pea and oat concentrates to restore the destroyed structure of the food system, and the isolate of soy proteins shows a rather low thixotropic ability. Other scientists also reported the tendency for the rheological properties of mixtures to deteriorate when soy protein isolate was used [45]. Despite the higher moisture-binding capacity of soy protein isolate, compared to other selected protein ingredients, it is not able to form low-energy bonds, which, after the destruction of the structure, show active self-renewal of the structure. It was proved [46] that in protein mixtures, gel formation occurs at a concentration of soy protein above 7.5 % and a processing temperature above 80 °C. A concentration of this protein at the level of 7.5–12.5 % using treatment at a temperature above 90 °C leads to phase separation, low viscosity, and a low yield point, while a concentration above 15 %, with a heat treatment at 90 °C, it demonstrated protein aggregation and the initial formation of a gel network. The causal relationship is that in this study, the concentration of soy protein isolate in the ice cream mixes was significantly lower, as was the temperature of the heat treatment. Together, these factors do not allow us to avoid the deterioration of the cohesive characteristics of the mixtures.

It was established [47] that pea protein concentrate (2–8 %) in a mixed protein suspension with skim milk (total mass fraction of protein – 5–11 %) provides an increase in viscosity as the mass fraction of dry substances in the system increases. However, the maximum levels of viscosity were recorded at a concentration of pea protein in the mixture of 7 %. In this study, an increase in viscosity was observed at a lower concentration of pea proteins (1–2 %), which may be related to both the synergism between the components of the ice cream mixture and a high enough mass fraction of dry substances (28.41–29.34 %). Another reason for the increase in viscosity when using pea proteins can be their low solubility, which leads to the formation of insoluble aggregates and, accordingly, the effective viscosity of food systems [48].

It can be concluded that unlike soy proteins, which also increase the viscosity of ice cream mixtures, pea proteins are able to form a strong gel network that has greater elasticity and strength [49]. A similar trend was observed when studying the viscous-elastic behavior of protein systems [50] consisting of whey and pea protein isolate, an increase in viscosity, pseudoplasticity, and elasticity was found when the mass fraction of pea protein in the mixtures increased.

For oat protein concentrate, an increase in plasticity is observed with an increase in pretreatment temperature. It was established that heat treatment at 120 °C improves the rheological properties of oat protein significantly more than processing at 90 °C [51]. This phenomenon can partially explain the decrease in the ability of oat protein concentrate to restore the structure in ice cream mixes, compared to pea protein.

However, increasing the elasticity of bonds and the formation of a strong gel network in ice cream mixtures does not always have a positive effect on the quality indicators of the finished product. An increase in the viscosity of mixtures, as well as relative density, by using proteins makes it difficult for them to be saturated with air, which reduces whipping. It was established [52] that the whipping ability of ice cream decreases from 50.50 % to 45.80 % with an increase in the concentration of oat proteins up to 2 %. A reduction in whipping from 33.15 % to 16.06 % also occurred when pea protein was used [19]. The addition of soy protein isolate (0.25–3.1 %) reduced this indicator from 33.34 to 19.38 % [53]. In this study, a slight increase in whipping was observed with the use of 1 % oat protein concentrate. The addition of 1–2 % pea protein concentrate also had a positive effect on the whipping value, however, at the maximum concentration, this indicator increased insignificantly. The difference in the obtained data may be associated with an increase in the viscosity of food systems and the complication of the freezing process.

The correlation between the indicators of resistance to melting and whipping is comparable to the studies of scientists who also reported an increase in the melting speed of ice cream when it is saturated with a larger volume of air [54, 55]. However, we also know the results of studies where ice cream with low whipping speed melted quickly, and ice cream with high whipping index had a tendency to decrease the speed of melting [56]. There are opinions that there is no interdependence between the index of whipping and resistance to melting [33, 57].

In general, information on the properties of hydrated plant proteins and colloidal solutions with them is comparable to the studies by other scientists [37–41]. At the same time, the results of the rheological behavior of ice cream mixtures with plant-based protein concentrates do not always coincide with previously established patterns [46, 47, 51], which is due to the difference in chemical composition between the studied food systems and their preparation methods. That is why when using such plant-based proteins in ice cream technology, it is necessary to take into account its recipe composition and the compatibility of components with proteins in order to achieve a certain technological effect.

Ice cream is a product of long-term storage at low temperatures, which determines the importance of the stability of all its components during the shelf life. For this reason, the prospect of further work consists in conducting a study of the physicochemical characteristics of ice cream with plant-based proteins during long-term storage.

A limitation of the study is that the mass fraction of proteins in plant protein supplements may be different and not just the same as in this study. This can certainly have different effects on ice cream quality indicators and should be investigated on a case-by-case basis.

Among the potential shortcomings of the study, we can single out the use of protein supplements with different degrees of purification (concentrates and isolates), which probably makes it somewhat difficult to compare their technological effect.

7. Conclusions

1. Soy protein isolate (543.8 %) and pea protein concentrate (511.6 %) have the highest moisture retention capacity. At the same time, in terms of the ability to form and stabilize foams in aqueous solutions with proteins, the best example is 1–2 % pea protein concentrate. With such a mass fraction of the protein additive, the foaming rate of the solution increases to 148.8–160.6 %, and foam stability to 15.2–17.1 min.

2. Plant-based proteins increase the effective viscosity of ice cream mixtures, however, the highest thixotropy of mixtures is observed when using 1–2 % pea protein concentrate (56.5–61.0 %) and 1–2 % oat protein concentrate (54.8–57.2 %). Our data make it possible to substantiate the reduction of the duration of maturation of mixtures with them to 8 hours. Soy protein isolate reduces the ability of mixtures to recover, except for the use of its maximum amount (2 %) and maturation for 16 hours.

3. Pea protein concentrate (1–2 %) increases the whipping ability of ice cream from 61.2 % to 69.4–73.7 %, and oat protein concentrate (1 %) to 63.6 %. Whey protein isolate (1–2 %), although it provides the highest values of resistance to melting, significantly reduces the curdling of ice cream, which makes its use possible. That is why the rational mass share of plant-based proteins in the composition of dairy ice cream is 1–2 % for pea protein concentrate, and 1 % for oat protein concentrate.

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 and the results reported in this paper.

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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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