Functional and technological properties of protein ingredients in whey ice cream

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Abstract

Introduction. This study explores rheological characteristics of mixes of whey ice cream with protein ingredients.

Materials and methods. The viscosity characteristics of the mixes were studied by the method of rotational viscometry. Foam overrun and foam resistance of ice cream mixes were determined using modified methods.

Results and discussion. The expediency of using protein ingredients in whey ice cream mixes to increase their nutritional value was shown. Addition of whey protein isolate in the amount of 3–5%, micellar casein, 3%, or whey protein concentrate, 3%, increased the foam overrun of whey ice cream mixes, while addition of soy protein isolate decreased it. The highest rate of foam resistance, 57.6–58.4%, was recorded for the mix with 3–5% of whey protein isolate.

Based on the results of the analysis of flow rheograms of ice cream mixes with various protein ingredients, they were classified as food systems with a coagulation structure, characterized by pronounced thixotropic properties. In the case of micellar casein, whey protein concentrate or whey protein isolate, the thixotropic ability of the mixes increases from 58.2% to 62.2–72.2%. Soy protein isolate does not show the specified technological activity.

The highest thixotropy of the mixes was observed for mixes with 3% micellar casein and 3–5% whey protein isolate due to their specific ability to form a spatial coagulation structure, which spontaneously restores the structure after destruction due to the presence of numerous low-energy bonds. Whey protein concentrate has a moderate effect on the rheological characteristics of the mixes, while the presence of soy protein isolate leads to a partial loss of the ability of the mixes to spontaneously restore the destroyed structure.

The possibility to increase the total protein content in ice cream from 3.45% to 6.02–7.81% due to the use of technologically effective milk-protein ingredients has been proven.

Conclusions. Micellar casein and whey protein isolate in the composition of whey ice cream mixes show high technological activity and significantly improve the quality indicators of the finished product.

Introduction

Whey ice cream is a frozen dessert, made on the basis of secondary dairy resources such as fresh or powdered whey (sweet or acid) (Goff, 2008; Kamińska-Dwórznicka et al., 2022). However, in case of using whey as a milk base, the level of total solids, in particular high-value whey proteins, is quite low (Barros et al., 2021; Jeličić et al., 2008). The high content of free water in whey ice cream mixes prolongs the ripening process and reduces its effectiveness due to the low viscosity of the mixes, which subsequently affects the freezing process and the quality indicators of the ice cream. To increase the content of solids in whey ice cream, it was proposed to use of hydrolyzed concentrates of demineralized whey (total solids, 40%; protein, not less than 4.6%; lactose, not more than 6.6%) as a basis (Osmak et al., 2021). Their use will increase the level of solids in ice cream to 39.61–49.61%, of which the mass fraction of protein is about 3.3%. However, further enrichment of ice cream with proteins to a content of 6–8% is appropriate both for improving the texture and significantly reducing the size of ice crystals, and for increasing the nutritional value of this product (Arslaner and Salik, 2020; Polishchuk et al., 2020).

In the process of ice cream production there is an additional mechanical impact on the mixes during such technological stages as dosing, packaging, transportation through pipelines and devices with moving working organs (Kasapoglu et al., 2023). The structural and mechanical properties of ice cream mixes with a low protein and fat content during processing can be significantly changed depending on various technological factors such as temperature (Goff et al., 2013), moisture content and its connection with the food material (Soukoulis et al., 2014), and pressure (Innocente et al., 2009). Therefore, to avoid a negative mechanical effect on the rheological characteristics of mixes with a low protein and fat content, it is necessary to improve their composition using ingredients with clearly expressed moisture-binding, stabilizing and foam-forming properties, namely polysaccharides and proteins (Cheng et al., 2015; Himashree et al., 2022).

Protein concentrates with protein content < 90% and isolates with protein content > 90%, such as whey, casein, and soy are natural techno-functional and enriching ingredients of animal or plant origin, which are widely used in the food industry (Day et al., 2022; Mykhalevych et al., 2022). The use of such protein additives during the preparation of whey mixes can contribute to an increase in their viscosity, foaming properties, which will affect the quality of ice cream during further production, and is also appropriate from the point of view of the popularity of protein-enriched products (Hossain et al., 2021; Sipple et al., 2022).

Soy protein isolates and whey protein concentrates are the most studied representatives of protein ingredients in food systems (Chen et al., 2019; Himashree et al., 2022). Saentaweesuk and Aukkanit (2019) reported that whey protein isolate added in the amounts 2.5% and 5% makes the taste of ice cream closer to the control sample and also it increases overrun and resistance to melting. Whey and soy protein additives are widely studied in traditional types of milk-based ice cream, but their additional use in classic whey ice cream with a low protein content of 1.28-1.41% is limited, in particular because whey ice cream is not a product of mass consumption, but belongs to the amateur type (Shevchenko et al., 2022; Young, 2007). Micellar casein due to a special production technology has high solubility, emulsifying and foaming abilities, so it is also a promising ingredient, but not widely used (Goff, 2022; Polishchuk et al., 2020).

Mixes for ice cream, in particular whey, belong to multicomponent systems (Schiraldi et al., 2019) with a complex structure, the nature of which changes under the influence of time-varying external mechanical stresses could only be investigated using rotational viscometry.

That is why the study of the main rheological characteristics of whey ice cream mixes with increased protein content is of great practical importance for obtaining an objective assessment of the process of forming quality indicators of whey ice cream at various stages of the technological process, in particular during low-temperature processing.

The aim of the present research was to study the functional and technological properties of protein concentrates and isolates of various origins in the composition of whey ice cream mixes.

Materials and Methods

Materials

Hydrolyzed demineralized whey concentrate, stabilization system Cremodan SE 406 (DuPont™, Danisco®), white crystalline sugar, vanilla and water were used to make whey ice cream mixes. Soy protein isolate 90% (ISOPRO 900EM-UPI, China), whey protein concentrate 70% (Hadyachsyr, Ukraine), micellar casein 85% (Ingredia Promilk, France), whey protein isolate (Spomlek, Poland) were chosen as protein ingredients.

Preparation of samples

The hydrolyzed concentrate of demineralized whey was mixed in drinking water and heated to a temperature of 40±5 °C, after which pre-weighed and mixed dry components were added. The mixes were stirred for 1–2 min, filtered and pasteurized at a temperature of 85±2 °C for 5 min. Homogenization was carried out under a pressure of 12.0±2.5 MPa using a laboratory homogenizer-disperser model 15M-8TA "Lab Homogenizer & Sub-Micron Disperser" (Gaulin Corporation, Massachusetts, USA). The homogenized mixes were cooled to a temperature of 4±2 °C and left for ripening for at least 12 hours.

Whey ice cream based on hydrolyzed concentrate of demineralized whey served as a control. The content of the stabilization system was chosen at the level of 0.6% in accordance with the manufacturer's recommendations. Protein ingredients were used in amounts from 3 to 11% in 2% increments. The applied ranges of the protein content in ice cream mixes provided the level of protein supply from 14.71 to 27.55%, which gives the right to consider this product as enriched with protein (more than 12%) or a source of protein (more than 20%) (Regulation (EC) No 1924/2006).

Methods

Determination of the chemical composition of mixes

Protein content in ice cream mixes was determined by the Kjeldahl method. Total solids content in samples was carried out by the arbitration method, the principle of which is to dry the sample, diluted with distilled water and mixed with sand, at a temperature of 102°C to a constant mass, followed by weighing to determine the mass of the residue.

Definition of foam overrun

After cooling to a temperature of 2–6 °C, the ice cream mixes were whipped for 5, 10, and 15 min with 5-min breaks according to the method of Lim et al. (2008). Foam overrun was determined as the ratio of the volume of the whipped mix to its initial volume, expressed as a percentage.

Determination of foam stability

The foam stability of experimental samples of ice cream mixtures was determined by the modified method of Philips L., according to which a container with a hole at the bottom was used for foam to drain after churning (Lim et al., 2008). The foam stability indicator was taken as the time during which 50% of the initial volume of the mix, which was used for whipping, is formed as a result of foam destruction.

Definition of rheological behavior

Viscosity-speed characteristics of ice cream mixes were determined on a rotary viscometer with a measuring system "cylinder-cylinder" by recording deformation of kinetic curves. Measurements were made at a temperature of 20°C. Shear stress τ (Pa) was measured at twelve values of the shear rate gradient D in the range 3–1312.2 s^{-1} during forward and reverse course (Bass et al., 2017).

The maximum effective viscosity of the almost 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 mixes (thixotropic ability) was determined in percent 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}) (Sapiga et al., 2021).

Statistical processing

Data were expressed as the mean with standard deviation of triplicate measurements. Statistical analysis was performed using the program Statistika 10.

Results and discussion

The control sample of the whey ice cream mix based on the hydrolyzed concentrate of demineralized whey had the following composition: total solids, 39.6%, of which fat was 0.74%, protein was 3.45%, stabilization system was 0.6%, and sugar was 9%.

The chemical composition of the experimental mixes of whey ice cream with protein additives was as follows: total solids, 42.6–50.6%; fat, 0.74–0.85%; protein, 6.02–13.57%; stabilization system, 0.6%; sugar, 9%.

The use of protein technological ingredients in the composition of ice cream is appropriate for increasing the foaming properties of ice cream mixes and improving the efficiency of the freezing process due to uniform and finely dispersed air saturation and the corresponding formation of a homogeneous and creamy structure of the product (Bahramparvar and Tehrani, 2011).

To study the effect of protein additives on the rheological properties of ice cream mixes, their foam overrun and foam resistance were determined (Table 1).

Table 1

Foaming properties of whey ice cream mixes

Ice cream mix with protein additive, %		Foam overrun, %			Foam stability, min		
		Time of whipping, min					
		5	10	15	5	10	15
Control	0	150.0±1.5	201.4±4.2	187.5±1.6	44.8±0.6	49.5±0.5	48.1±1.3
Whey protein isolate	3	142.5±5.2	160.0±5.8	162.5±1.4	41.0±0.8	42.2±0.1	42.8±0.8
	5	135.8±1.4	148.2±3.8	139.7±2.3	34.4±0.4	36.7±1.2	38.5±0.6
	7	129.4±0.9	133.5±1.9	130.6±1.7	32.4±1.1	34.6±0.5	35.0±0.8
	9	126.8±3.3	125.7±2.4	120.7±3.4	29.1±0.4	30.8±1.2	32.8±1.0
	11	115.1±1.8	114.3±3.8	110.7±2.5	28.2±0.2	29.4±1.2	31.6±0.9
Micellar casein	3	216.2±0.4	229.7±1.9	221.6±1.8	46.9±0.5	55.8±0.3	54.9±0.5
	5	197.4±4.1	210.5±1.4	207.0±3.0	44.1±1.2	45.7±0.8	48.5±0.6
	7	168.0±5.2	179.6±2.5	170.8±2.2	39.8±0.7	40.6±0.8	38.3±1.2
	9	144.3±4.4	150.4±1.0	145.8±1.4	37.0±0.7	38.8±0.3	40.2±1.1
	11	138.9±0.7	142.7±2.5	139.1±2.8	32.8±1.0	34.5±0.9	35.9±0.3
Whey protein concentrate	3	185.0±1.6	205.0±1.5	200.0±3.6	44.8±1.1	46.3±0.6	46.2±0.9
	5	169.5±2.3	184.8±3.4	178.2±0.9	37.8±0.8	39.5±0.2	38.7±0.8
	7	153.8±1.9	162.7±1.1	159.5±0.7	35.1±0.5	36.4±0.3	35.8±1.1
	9	139.5±1.7	145.7±3.0	141.2±1.8	32.5±0.9	33.6±1.0	31.4±0.5
	11	122.4±2.6	124.8±1.8	119.3±2.8	29.5±0.1	30.2±0.6	30.0±0.6
Whey protein isolate	3	203.3±1.7	236.7±2.5	246.7±4.7	48.4±0.7	58.4±0.2	61.9±0.4
	5	192.1±2.0	220.4±3.2	221.5±1.2	45.9±0.8	57.6±0.9	59.3±1.0
	7	178.5±1.4	206.4±0.5	192.0±2.4	44.8±0.1	55.7±0.4	53.8±0.8
	9	148.6±5.4	166.0±1.1	156.2±3.9	41.3±1.9	44.2±1.2	42.0±1.4
	11	139.4±0.3	144.5±1.0	140.7±1.9	38.4±1.0	39.6±1.2	38.0±0.3

The use of whey protein isolate, 3%, led to a decrease in the foaming properties of the mixes, compared to the control. Micellar casein in the first five minutes of whipping provided the highest foaming of all protein ingredients, however, after further whipping for 10 min, this value was less than for 3% whey protein isolate, and after 15 min it decreased, while for the whey proteins isolate, on the contrary, increased.

It is known that micellar casein has a foaming ability (Zhao et al., 2022), however, due to the instability of the formed bubbles due to the weaker interfacial elasticity of casein, this did not ensure the formation of strong bonds that form a dense protein matrix (Sato et al., 2021), similar for systems with whey protein isolate, which also confirm the obtained foam resistance values. Xinqi Zhao et al. (2022) in the study of aqueous solutions with whey protein isolate, which were treated with ultrasound, showed an increase in their foam ability from 60.06 to 143%. In our case, the obtained values were significantly higher, because studied ice cream mixes are multicomponent food systems. However, homogenization under pressure can also partially increase the foaming properties of mixes (Jambrak et al., 2008). The effect of whey protein concentrate, 3%, is more moderate compared to micellar casein and whey protein isolate, but it significantly increases foaming and foam resistance compared to the control.

The appearance of whipped whey mixes with the highest foam overrun and foam resistance is shown in Figure 1.

a b c

Figure 1. Whipped whey ice cream mixes:
a, control, b, with 3% of micellar casein, c, with 3% of whey protein isolate

Viscosity-speed characteristics were studied in mixes that had the highest foaming abilities (Table 2).

Table 2

Viscosity-speed characteristics of whey ice cream mixtures

Ice cream mixture	**Effective viscosity (mPa·s) under variable shear rate gradient**			**The time of ultimate destruction of the structure (γ=1312.2 s^{-1}), min**	**The degree of structure recovery, %**
	$\gamma = 3$ s^{-1} (forward course)	$\gamma =$ 1312.2 s^{-1}	$\gamma = 3$ s^{-1} (reverse course)		
Control	601.0±11.8	20.0±1.0	350.3±10.5	5.5±0.2	58.2
3% SPI*	569.1±10.5	41.8±1.1	323.8±7.4	5.3±0.1	56.9
3% MC	650.1±15.7	46.1±2.2	430.0±13.0	6.7±0.3	66.1
5% MC	636.9±14.5	45.6±1.4	407.2±11.1	6.4±0.1	63.9
3% WPC	571.7±9.2	38.4±1.7	394.5±4.8	5.9±0.2	62.2
3% WPI	676.1±12.6	49.7±2.1	488.4±17.2	7.5±0.2	72.2
5% WPI	623.4±17.4	47.4±1.1	421.4±12.6	7.2±0.3	67.6

Note: *SPI is whey protein isolate; MC is micellar casein; WPC is whey protein concentrate; WPI is whey protein isolate.

The high content of solids in the ice cream mixes ensured a high degree of thixotropy, 58.2%, even for the control sample. In the case of using protein ingredients (micellar casein, whey protein concentrate, whey protein isolate), the thixotropy of the mixes increased from 58.2% to 62.2–72.2%, except for the sample with soy protein isolate.

Thus, whey protein isolate showed the greatest ability to restore whey mixes of ice cream, which is associated with its high solubility (Tavares et al., 2019), as well as the formation of elastic bonds that increase the strength of the gel network, stimulating the formation of more intense intermolecular interactions. Micellar casein is also capable of forming a gel network (Zhao et al., 2022), but it is not as strong as in case of whey protein isolate use (de Castro et al., 2017). Although whey protein concentrate exhibits thixotropic ability, it is less than in the case of micellar casein and whey protein isolate, which is due to lower degree of its purification. Other scientists also reported about ability of soy protein isolate to deteriorate the rheological properties of mixtures (Zhang et al., 2021). Soy protein isolate, compared to other selected protein ingredients, is unable to form energy bonds that, after the destruction of the structure, reveal active restoration of the structure.

The dynamics of changes in the effective viscosity of samples that show the highest thixotropy during rheometric measurement are shown in Figure 2.

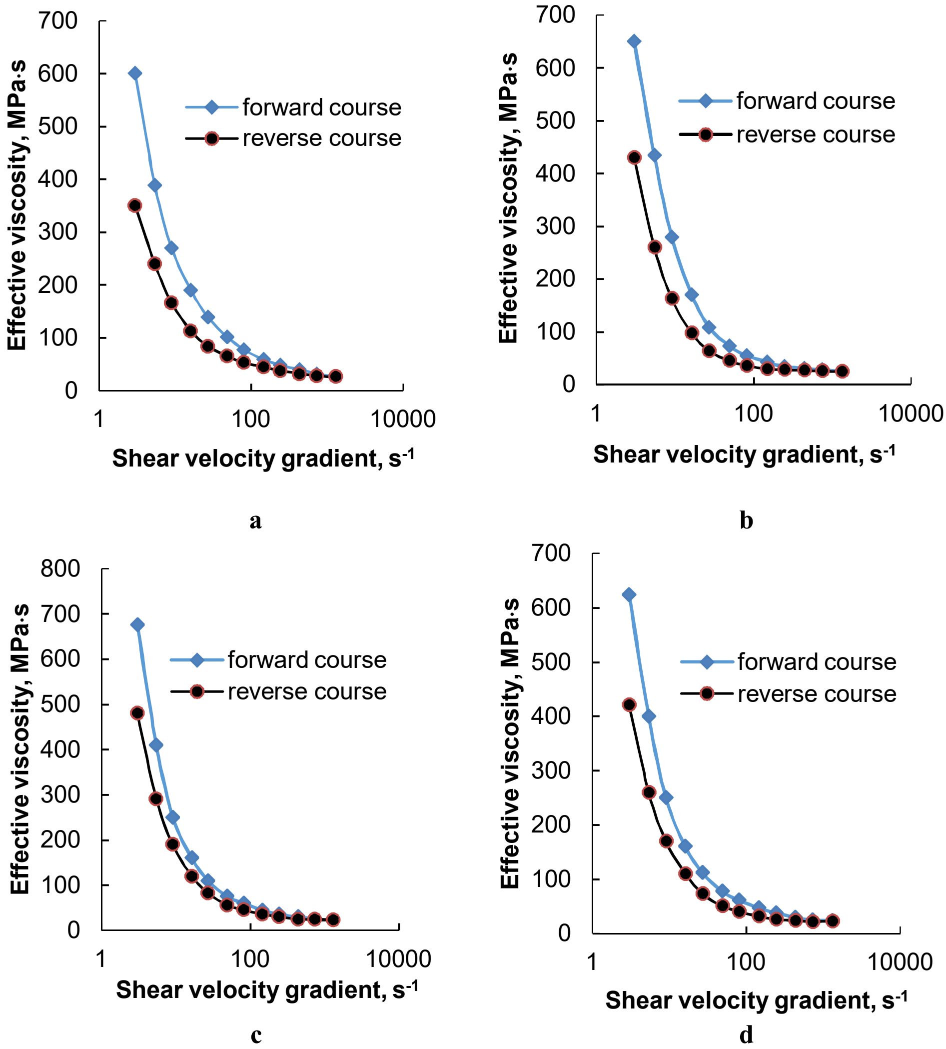

Figure 2. Flow rheograms of whey ice cream mixes:
a, control; b, ice cream mix added with micellar casein, 3%;
c, ice cream mix added with whey protein isolate, 3%;
d, ice cream mix added with whey protein isolate, 5%

The analysis of flow rheograms of the studied samples indicates the ability of micellar casein added in amount of 3% to more effectively restore the structure of food systems than for the control sample. Ice cream mixes (Fig. 1) belong to systems with a pronounced coagulation structure, but samples with whey protein isolate, 3–5%), show the highest thixotropic properties. This effect could be explained by the specific functional properties of whey proteins, in particular, their ability to form a spatial coagulation structure capable of spontaneous restoration of the structure after destruction in the presence of numerous low-energy bonds.

Conclusions

Micellar casein and whey protein isolate in the composition of whey ice cream mixes show technological activity and increase the foam overrun and foam resistance of the finished product. Thus, the foam overrun of the mix with micellar casein, 3%, was 229.7%, and with whey protein isolate, 3-5%, was 221.5–246.7%. The highest rate of foam resistance, 57.6–58.4%, was recorded with the use of 3–5% whey protein isolate.

The highest thixotropic ability was observed for mixes containing 3% micellar casein, 66.1%, and 3–5% whey protein isolate, 67.6–72.6%. The use of whey protein concentrate has a moderate effect on the rheological characteristics of mixes. The presence of soy protein isolate leads to a partial loss of the mixture's ability to self-restore the destroyed structure.

The perspective of further research is to determine the quality indicators of samples of whey ice cream with protein additives at various stages of low-temperature processing.

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