Influence of whey concentrates and carbohydrate ingredients on rheological and physicochemical parameters of reduced fat sour cream

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Keywords:

Sour cream
Whey concentrates
Rheology
Syneresis

Article history:

Received 18.02.2024
Received in revised form 21.05.2024
Accepted 28.06.2024

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DOI: 10.24263/2310-1008-2024-12-1-3

Abstract

Introduction. The objective of this research is to study the patterns of the rheological and physicochemical characteristics of reduced fat sour cream enriched with whey protein concentrates in the presence of mono- and polysaccharides.

Materials and methods. The study examined samples of 10% fat sour cream enriched with whey protein concentrate obtained by ultrafiltration, and hydrolyzed concentrate of demineralized whey in the presence of mono- and polysaccharides. Viscosity characteristics were determined using a rotational rheometer "Kinexus Pro+"; water activity was determined using an analyzer "HygroLab2".

Results and discussion. Whey protein concentrate and hydrolyzed concentrate of demineralized whey are technologically active ingredients that enhance the rheological characteristics of sour cream with a fat content of 10% and its capacity to retain moisture. Prolonged heat treatment of cream before fermentation at 95–98 °C for 3 h has a significant impact on the physicochemical and viscosity characteristics of 10% fat sour cream due to the thermal denaturation of whey proteins. The incorporation of monosaccharides in the hydrolyzed concentrate of demineralized whey, coupled with the introduction of a glucose-fructose syrup into reduced fat sour cream, has been observed to diminish its structuring and thixotropic potential, along with its water activity. The addition of 0.5% guar gum resulted in a notable enhancement in the rheological parameters, reaching their maximum values. The effective viscosity was observed to be 127.209 Pa·s at a shear rate gradient of 0.1 s^{-1}, while the degree of structure recovery during the reverse sweep reached 23.23%. The compatibility of oat β-glucan at a concentration of 0.5% in the presence of 1% whey protein concentrate in reduced fat sour cream was found to be incompatible, as evidenced by an abnormal deterioration of its rheological and physicochemical characteristics. This phenomenon may be attributed to the inhibition of the cream fermentation process at the selected concentration of the polysaccharide or the partial destruction of β-glucan during the homogenization of cream prior to fermentation, which results in the formation of a mobile layer of a colloidal solution of this polysaccharide between protein macromolecules.

Conclusions. The present study has established the regularities of changes in the structural-mechanical and physicochemical parameters of reduced fat sour cream enriched with whey proteins in the presence of monosaccharides and polysaccharides of different origin.

Introduction

Sour cream is produced through the fermentation of cream with varying fat content. The physicochemical and rheological characteristics of sour cream differ significantly depending on the fat content, with notable changes in consistency. In particular, the consistency transitions from viscous and homogeneous to structured with a near complete loss of fluidity (Meunier-Goddik, 2012). A specific feature of the rheological characteristics of sour cream is that it exhibits a viscosity anomaly that depends on the velocity and temperature gradient (Seo, 2022). Reduced fat sour cream with a fat content of 10% differs from full-fat types in terms of its liquid consistency, high acidity, and satisfactory moisture retention (Odnorog et al., 2018). To enhance the physicochemical attributes of reduced fat sour cream, moisture-binding structuring ingredients derived from non-dairy sources, such as carrageenan, guar gum, modified starches, and cellulose derivatives, are frequently employed (Meunier-Goddik, 2012). Danylenko et al. (2020) proposed the addition of 0.01–0.03% dry banana puree to the sour cream composition as a mean of enhancing its rheological characteristics. However, the most appropriate solution is the incorporation of dairy ingredients, specifically whey protein concentrates, into natural reduced fat sour cream. The addition of protein concentrates can enhance the consistency and moisture retention capacity of fermented dairy products, while also increasing their biological value (Luck et al., 2013; Seo et al., 2023).

The role of protein in the formation of the structure of low-fat sour cream with a fat content of 10 to 15% is of primary importance. As reported by Narvhus et al. (2019), an acidic protein gel, comprising casein and denatured whey proteins, forms a structured matrix that incorporates fat globules. It was observed that as the fat content exceeds 20%, acid gels contain a reduced proportion of coagulated free protein. In fermented cream with a fat content of 35%, the structural network is comprised almost entirely of aggregated fat globules covered with protein. It can be reasonably deduced that milk protein in the concentrates will have a significant impact on the physicochemical and rheological characteristics of reduced fat sour cream.

Appliction of whey proteins in different food technologies is well known (Ivanov et al., 2021; Kochubei-Lytvynenko et al., 2022, 2023; Wang et al., 2024). The results of previous studies have demonstrated the feasibility of utilizing whey protein concentrate (WPC) and hydrolyzed concentrate of demineralized whey (HCDW) in sour cream with a fat content of 10% (Mykhalevych et al., 2022). Furthermore, no research has been conducted into the impact of different heat treatment methods applied to cream prior to fermentation. Additionally, the role of whey protein concentrates, including their potential combined use with mono- and polysaccharides, in influencing the formation of structural, mechanical, and physicochemical characteristics in reduced fat sour cream remains undetermined.

The aim of the study was to identify the patterns of formation of rheological and physicochemical characteristics of 10% fat sour cream enriched with whey protein concentrates in the presence of mono- and polysaccharides.

Materials and methods

Raw materials

Samples of sour cream with a fat content of 10% of the following composition were studied:

- control (sour cream without additives);
- sample 1 (baked sour cream);
- sample 2 - sour cream with hydrolyzed concentrate of demineralized whey (HCDW);
- sample 3 - sour cream with whey protein concentrate (WPC);
- sample 4 - sour cream with whey protein concentrate (WPC) and β-glucan;
- sample 5 - sour cream with whey protein concentrate (WPC) and glucose-fructose syrup (GFS);
- sample 6 - sour cream with whey protein concentrate (WPC) and guar gum.

The following is a description of the reasons to select the samples under study.

Sample 1 is of scientific interest with regard to the investigation of the impact of prolonged high-temperature cream processing on the viscosity characteristics of baked sour cream, which is distinguished by a creamy color and a pleasant flavor resulting from the Maillard reaction (Lohinova and Petrusha, 2024; Xiang et al., 2021).

Samples 2 and 3 were selected based on the findings of previous studies (Mykhalevych et al., 2022), which identified the most promising milk-protein concentrates (WPC and HCDW) for the enrichment of reduced fat sour cream. These concentrates were found to enhance the biological value of the product and improve its consumer characteristics. However, further in-depth study is required to fully understand these effects.

Samples 4–6 were created because protein-enriched reduced fat sour cream is also intended to be used in the production of structured dessert sour cream products. Therefore, it is advisable to study the combined effect of milk protein concentrates (for example, WPC), monosaccharides (glucose-fructose syrup) and polysaccharides (β-glucan and guar gum) on the structural, mechanical, and physicochemical properties of the samples.

Samples preparation

A control sample of sour cream with a fat content of 10% was obtained from normalized cream, which was prehomogenized at 10 MPa and a temperature of 60–65 °C using a laboratory homogenizer-disperser model 15M–8TA "Lab Homogenizer & Sub-Micron Disperser" (GAULIN CORPORATION, Massachusetts, USA), pasteurized at 85–90 °C for 5 min and cooled to an inoculation temperature of 28–32 °C. An activated starter preparation (TM "Vivo", Ukraine) containing *Lactococcus lactis, Lactococcus cremoris, Lactococcus diacetylactis,* and *Streptococcus thermophilus* was used for cream incubation.

The duration of fermentation was 7–8 hours to pH 4.6. The fermented samples were cooled to 4±2 °C, matured for 24 hours, and stored at the same temperature for 5 days.

To prepare the experimental sour cream, the protein concentrates and carbohydrate-containing ingredients were pre-hydrated or dissolved in cream at a ratio of 1:10 in cream heated to 40 °C and then added to the remaining cream with subsequent stirring. The resulting mixes were subjected to mechanical and heat treatment as described for the control sample.

In order to obtain baked sour cream, the cream was preliminarily subjected to a prolonged heat treatment (180 min at 96±1 °C) to produce a creamy brown color, a characteristic nutty taste and a pronounced aroma in the sample (Mandiuk et al., 2024).

The following milk protein ingredients were selected:

– whey protein concentrate obtained by ultrafiltration (WPC) (composition: solids - 94%, protein - 80%, carbohydrates - 7%, fat - 7%);
– hydrolyzed concentrate of demineralized whey (HCDW) with a solids content of 40% (degree of lactose hydrolysis not less than 85%). It was obtained through the reconstitution in water of demineralized whey powder with a demineralization level of 90% (ash - no more than 2.5%, lactose - no less than 79%, and protein content - no less

than 10.7% in terms of solids), in accordance with the developed technology (Osmak et al., 2021).

For the hydrolysis of lactose in the 40% whey concentrate, the following preparations were employed:

– a liquid preparation of β-D-galactosidase-hydrolase "GODO-YNL2" (Danisco, Denmark) with a recommended dosage of 100 g of the preparation per 100 liters;
– the single-strain lyophilized starter "*L. acidophilus* LYO 50 DCU-S" (Danisco, Denmark) at a recommended dosage of 5 g of the preparation per 100 liters of milk.

At a specified degree of lactose hydrolysis (at least 85%), the demineralized whey concentrate contains approximately 26.2% monosaccharides, 4.6% lactose, and 10.7% protein. Therefore, together with 30% of the concentrate, 7.86% of the monosaccharides, 1.38% of the lactose and 3.21% of the protein are added to the sour cream.

The contents of WPC and hydrolyzed whey concentrate in the samples were 1.0% and 30.0%, respectively, according to the recommendations of Mykhalevych et al. (2022), resulting in a total protein content of 3.38% and 3.22% (the control sample of sour cream had a protein content of 2.6%).

The following natural monosaccharides and polysaccharides were utilized: β-glucan extracted from oats (Shanxi, China,) and guar gum (Neelkanth Polymers, India) in the amount of 0.5%, as well as glucose-fructose syrup GFS-42 (Intercorn Corn Processing Industry, Ukraine) in the amount of 12.1%. The selected con tent of GFS-42 (at least 65% monosaccharides) contributes at least 7.8% of monosaccharides to the sour cream, which is comparable to the amount of monosaccharides in the hydrolyzed whey concentrate added to the sour cream.

Polysaccharide concentration was chosen according to generally accepted recommendations (Seo, 2022).

Experimental procedure

The effective viscosity and water activity were determined in the prepared samples of sour cream of different chemical composition after aging for 24 h at 4±2 °C. The degree of syneresis was determined within 5 days.

Research method

The acidity of the fermented sour cream samples was determined by the potentiometric method using a laboratory analyzer pH/MV/ISE/Temp ADWA AD1200 ATC.

Water activity (Aw) in sour cream samples was determined using a water activity analyzer "HygroLab2" (Rotronic, Switzerland) at 20 °C. The instrument was pre-calibrated with a special humidity standard (95% HR). Water activity, with a measurement accuracy of ± 0.001 Aw units, was expressed as values from 0.00 to 1.00 Aw (0–100% rh).

The viscosity of sour cream samples was measured using a rotational rheometer Kinexus Pro+ (Malvern Instruments Ltd, United Kingdom). The upper geometry C25 DIN L0142 SS (cylinder) and the lower geometry PC25 DIN C0350 AL were chosen for the study. Before measuring the rheological properties, the sour cream samples were heated to the temperature of product consumption (10 °C) and gently mixed for 30 s. The samples were placed in a cylinder, the upper geometry was lowered, they were kept for 5 minutes and viscosity curves were determined for forward and reverse sweep at changes in shear rate from 0.1 to 400 s^{-1} and from 400 to 0.1 s^{-1}. The degree of recovery of the structure of the sour cream samples was calculated as a percentage of the effective viscosity at the end of the measurement at a shear rate gradient of $\gamma = 0.1\ s^{-1}$ (reverse sweep), taking the effective viscosity of the practically intact structure at the beginning of the measurement ($\gamma = 0.1\ s^{-1}$) as 100%.

The syneresis of sour cream clots was determined by centrifuging calibrated tubes containing mixed samples of 25 cm³ for 20 min at 1000 rpm and 20 °C using a laboratory centrifuge Sigma 2-6E (Germany). The volume of whey separated was expressed in cm^3 per 100 g of product (Polischuk et al., 2020). Samples were analyzed after ripening and on 1st, 3rd and 5th days of storage.

Statistical processing

All results with 3–5 times replication were statistically processed using the software Statistika 10. Diagrams were created in Microsoft Excel 2016.

Results and discussion

Study of the viscosity characteristics of sour cream

The effective viscosity of sour cream samples was measured in the range of changes in the shear rate gradient during the forward stroke, from the minimum value ($\gamma = 0.1\ s^{-1}$) to the maximum value ($\gamma = 400\ s^{-1}$). The samples were held under these conditions until the steady-state viscosity of the maximally destroyed structure was reached. Subsequently, the viscosity of the samples was measured during the reverse stroke, wherein the shear rate gradient was reduced from maximum to minimum values.

The effective viscosity of the samples in the most dynamic range of changes in the shear rate gradient ($\gamma = 0.1–10\ s^{-1}$), as well as at the maximum ($\gamma = 400\ s^{-1}$) and minimum shear rates ($\gamma = 0.1\ s^{-1}$) at the end of the measurement are presented in Table 1.

Table 1

Effective viscosity of sour cream samples at a variable shear rate gradient (Pa·s)

Samples	Shear rate gradient, γ, s^{-1}				
	0.1 (forward sweep)	1 (forward sweep)	10 (forward sweep)	400	0.1 (reverse sweep)
Control	89.981 ±2.924	5.609 ±0.133	2.402 ±0.102	0.117 ±0.001	16.940 ±1.503
Sample 1	99.121 ±3.031	13.420 ±0.429	3.461 ±0.141	0.119 ±0.001	13.332 ±1.111
Sample 2	115.882 ±3.791	11.053 ±0.371	3.496 ±0.152	0.122 ±0.001	23.202 ±1.395
Sample 3	119.990 ±4.015	15.372 ±0.411	3.639 ±0.182	0.151 ±0.001	25.905 ±1.582
Sample 4	87.680 ±2.684	9.501 ±0.350	3.845 ±0.148	0.176 ±0.001	7.201 ±0.214
Sample 5	105.050 ±3.721	8.703 ±0.262	1.907 ±0.100	0.076 ±0.001	13.600 ±0.831
Sample 6	127.209 ±3.932	20.336 ±0.81	4.033 ±0.182	0.183 ±0.005	29.548 ±1.460

The data indicate that all samples of sour cream exhibited the most significant structural destruction within the range of shear rate changes from 0.1 to 1 s^{-1}, with moderate destruction observed within the range from 1 to 10 s^{-1}. The highest viscosity was observed for sample 6, which contained a combination of whey protein concentrate (WPC) and guar gum. As anticipated, the milk protein concentrates in sour cream (samples 2 and 3) demonstrated comparable structuring capabilities due to the enhanced coagulation activity of fermented mixtures enriched with whey proteins, reaching a total protein content of 3.22% (sample 2) and 3.38% (sample 3), respectively. This observed effect correlates with the data presented by Sturaro et al. (2014).

The prolonged high-temperature treatment of cream (sample 1) due to increased thermal denaturation of whey proteins resulted in an increase in the viscosity of the sour cream compared to the control sample. This phenomenon can be attributed to the covalent interaction of denatured whey proteins with κ-casein on the surface of protein casein micelles. Denatured whey proteins serve as a binder between casein micelles, thereby facilitating the more efficient formation of an acidic protein gel (Lucey, 2016). It is established that fresh fermented milk products made from milk thermally processed at high temperatures are more viscous and have a lower tendency to release whey (Timothy, 2021). These characteristics were confirmed in the present study. However, the experimental confirmation of the latter trait remains to be conducted.

The distinctive characteristics of the joint structuring effect of whey protein concentrate and mono- and polysaccharides in sour cream warrant a separate discussion. To conduct a comparative analysis of the efficacy of their combined use, the dynamics of changes in sour cream viscosity during rheometric measurement at a variable shear rate were investigated using the example of control and test samples 3–6, as illustrated in Figure 1.

Monosaccharides and polysaccharides exert a markedly disparate influence on the viscosity characteristics of sour cream. Therefore, monosaccharides present in the composition of glucose-fructose syrup exert a slight reduction in the effective viscosity of an almost intact acidic milk-protein gel at a shear rate gradient of 0.1 s^{-1}. An increase in the destructive force of the shear rate to 1 and 10 s^{-1} demonstrates a notable weakening of intermolecular forces, with the degree of destruction increasing by 1.17 and 1.9 times, respectively. The effective viscosity of the practically destroyed structure at a shear rate of 400 s^{-1} is 0.151 (Pa·s) for the sample with WPC, and only 0.076 (Pa·s) for the sample with whey protein concentrate and glucose-fructose syrup. The observed effect can be explained by the presence of a layer of mobile monosaccharide molecules between the protein micelles, which probably reduces the strength of intermolecular bonds in the protein clot. A comparable effect was observed when comparing sample 1, which contains monosaccharides in hydrolyzed whey concentrate, with sample 2, which contains whey protein concentrate (WPC). However, the effect was less pronounced in the latter sample. The detrimental impact of monosaccharides is mitigated by the incorporation of whey proteins in the hydrolyzed whey concentrate into the sour cream sample.

In contrast to monosaccharides, the presence of polysaccharides, in particular guar gum, has a notable impact on the viscosity characteristics of sour cream. In this instance, guar gum, a high-molecular-weight compound, serves to reinforce the total intermolecular bonds within the protein gel, thereby forming a more stable structure over time at a variable shear rate. The structuring effect of guar gum has also been observed in sour cream (Mudgil et al., 2014), yogurt (Lee et al., 2016), and ice cream (Javidi et al., 2016).

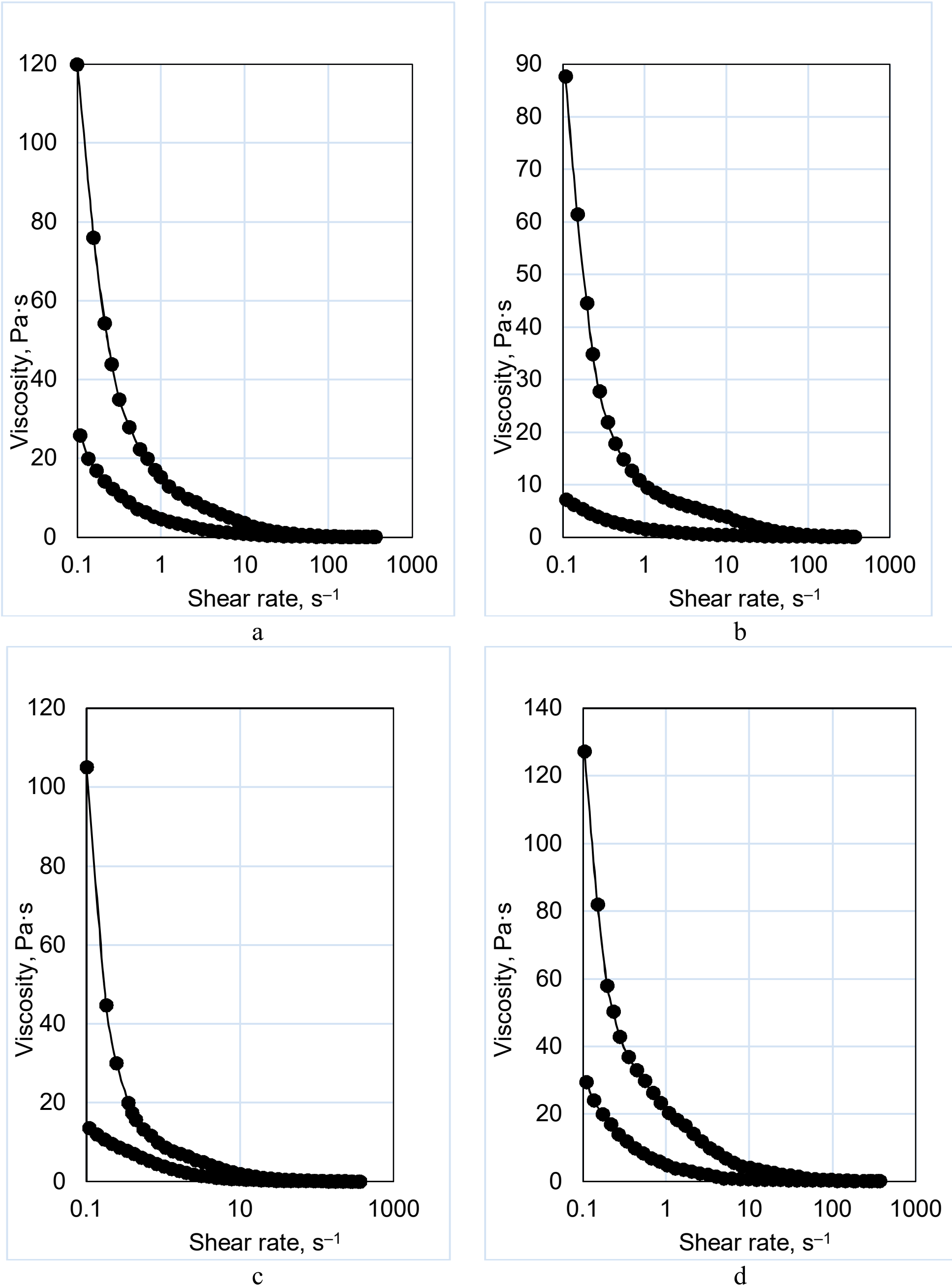

Figure 1. Changes in the effective viscosity of sour cream samples during rheometric measurement:
a – sample 3 (sour cream with whey protein concentrate;
b – sample 4 (sour cream with whey protein concentrate and β-glucan);
c – sample 5 (sour cream with whey protein concentrate and glucose-fructose syrup;
d – sample 6 (sour cream with whey protein concentrate and guar gum)

Despite the well-known functional and technological properties of β-glucans, in particular, their ability to form and stabilize the foamy structure of ice cream, prevent the separation of free moisture in the production of cheese, and mimic the presence of fat in low-fat products (Mykhalevych et al., 2022), this polysaccharide was found to be incompatible with sour cream as a structuring ingredient. The addition of β-glucan to sour cream, even in the presence of whey protein concentrate, resulted in the lowest effective viscosity values among all samples. This anomalous effect can be attributed to the distinctive physicochemical characteristics of this polysaccharide, the inhibition of the cream fermentation process, and the potential disruption of its macromolecules during the homogenization of cream mixtures prior to fermentation. A comparable outcome was documented by Zagorska et al. (2013) in the context of chitooligosaccharide. Further studies are required to investigate this phenomenon in greater depth.

Table 1 presents the degree of structure recovery observed in the process of reducing the destructive force during the reverse measurement when the shear rate was changed from 400 s^{-1} to 0.1 s^{-1} for all sour cream samples. The calculated results are illustrated in Figure 2.

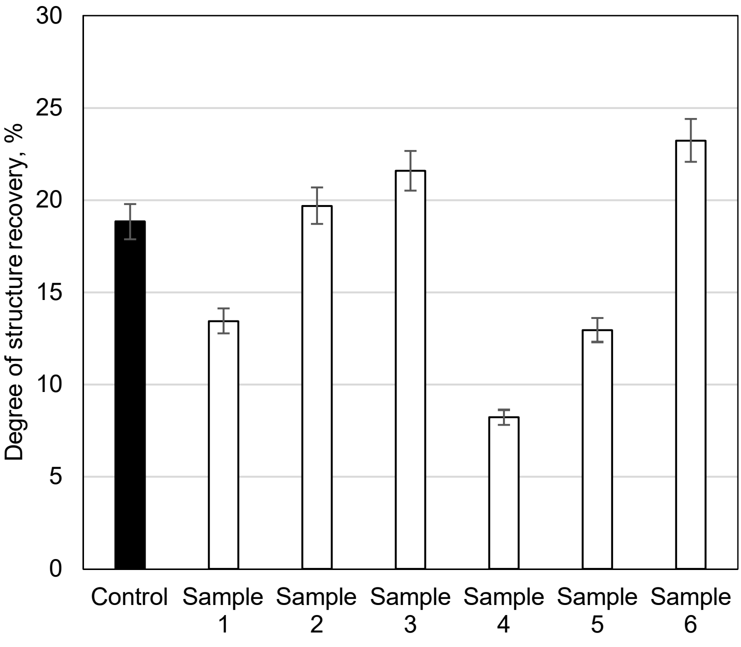

Figure 2. Degree of structure recovery of sour cream samples with 10% fat content and different chemical composition

Control (sour cream without additives);
Sample 1 (baked sour cream);
Sample 2 - sour cream with hydrolyzed concentrate of demineralized whey (hcdw);
Sample 3 - sour cream with whey protein concentrate (wpc);
Sample 4 - sour cream with whey protein concentrate (wpc) and β-glucan;
Sample 5 - sour cream with whey protein concentrate (WPC) and glucose-fructose syrup (GFS);
Sample 6 - sour cream with whey protein concentrate (WPC) and guar gum.

As illustrated in Figure 2, the examined food systems exhibit thixotropic behavior, with a considerable range of variation. It is noteworthy that the control sample exhibits a relatively high capacity for spontaneous structural restoration, with values exceeding those observed for samples 2, 3, and 6. This is attributed to the increased protein content, including the combination with guar gum. Concurrently, the presence of monosaccharides in sample 5 and the excessive denaturation of whey proteins during the prolonged heat treatment of cream in sample 1 (Polishchuk et al., 2023) to some extent impede the effective restoration of the sour cream structure. The addition of β-glucan to sour cream, as seen in sample 4, may have an adverse effect on the thixotropic ability of the resulting product. This is due to the probable loss of its structuring ability during homogenization, as previously discussed, as well as the obstruction of contact between protein macromolecules.

Water activity and the degree of syneresis in sour cream samples with different protein and carbohydrate composition

The subsequent phase of the study focused on examining the water activity and the capacity of protein-fat clots in sour cream samples with varying chemical compositions to retain moisture. These indicators are of significant importance for the formation of quality indicators in sour cream, and can be correlated with its chemical composition and rheological characteristics.

The water activity of the sour cream samples is illustrated in Figure 3.

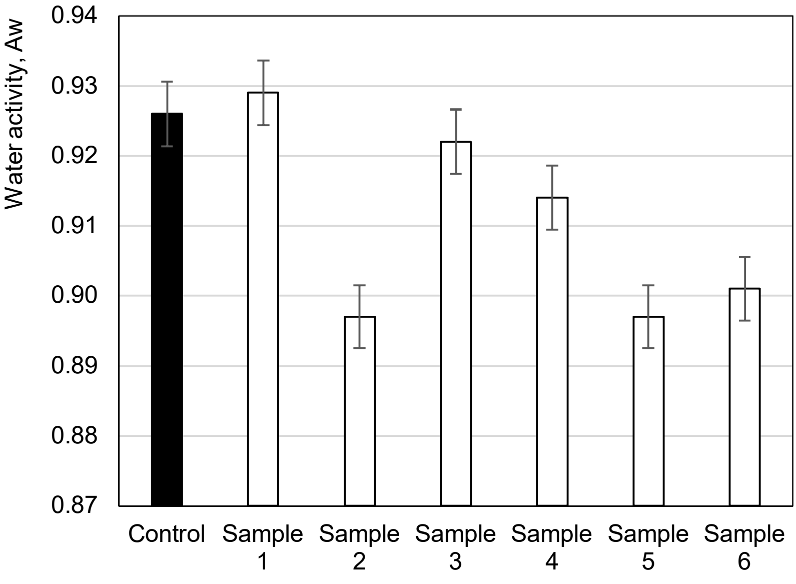

Figure 3. Water activity in the test samples of sour cream

Control (sour cream without additives);
Sample 1 (baked sour cream);
Sample 2 - sour cream with hydrolyzed concentrate of demineralized whey (hcdw);
Sample 3 - sour cream with whey protein concentrate (wpc);
Sample 4 - sour cream with whey protein concentrate (wpc) and β-glucan;
Sample 5 - sour cream with whey protein concentrate (WPC) and glucose-fructose syrup (GFS);
Sample 6 - sour cream with whey protein concentrate (WPC) and guar gum.

The water activity in the sour cream samples is notably elevated, ranging from 0.897 (samples 2 and 5 containing monosaccharides) to 0.929 (sample 2, baked sour cream). With regard to the sample of baked sour cream exhibiting the highest water activity, it can be posited that the prolonged and high-temperature processing of cream may result in the excessive coagulation of whey proteins, thereby reducing the moisture retention capacity of sour cream. This hypothesis will be tested in the subsequent series of experiments. Therefore, all sour cream samples can be classified as high-moisture products that are not capable of long-term storage (Plotnikova et al., 2021). It is therefore necessary to develop further technological measures to reduce the water activity in sour cream in order to control the intensity of various physicochemical, biochemical, and microbiological processes during the storage of protein-enriched sour cream.

Another crucial attribute of sour cream is its capacity to retain moisture within the protein-fat gel. The results of determining the syneretic ability of sour cream samples of different chemical composition after ripening and during storage for up to five days are presented in Figure 4.

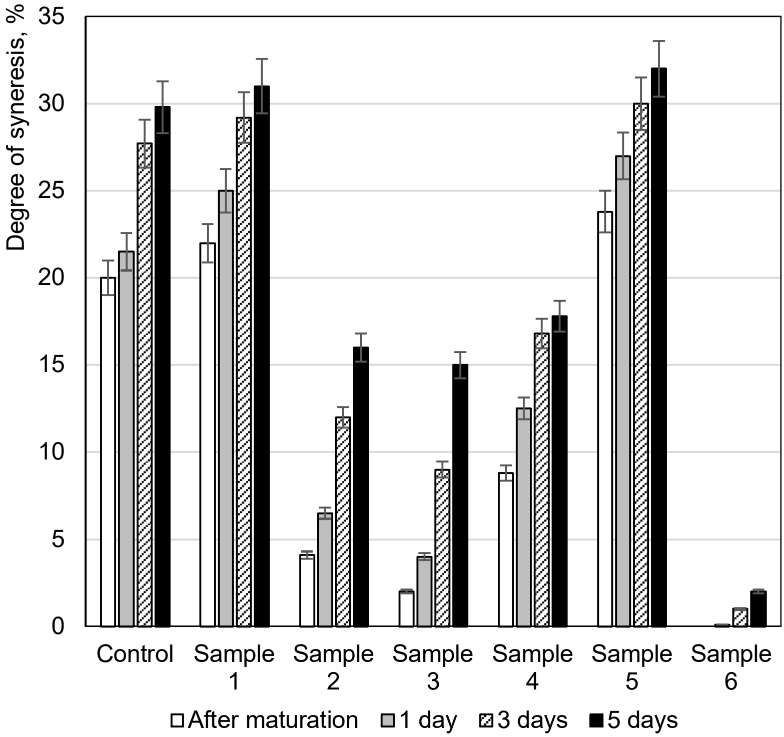

Figure 4. Degree of syneresis of sour cream samples of different chemical composition during storage

Control (sour cream without additives);
Sample 1 (baked sour cream);
Sample 2 - sour cream with hydrolyzed concentrate of demineralized whey (hcdw);
Sample 3 - sour cream with whey protein concentrate (wpc);
Sample 4 - sour cream with whey protein concentrate (wpc) and β-glucan;
Sample 5 - sour cream with whey protein concentrate (WPC) and glucose-fructose syrup (GFS);
Sample 6 - sour cream with whey protein concentrate (WPC) and guar gum.

The sample containing whey protein concentrate and guar gum (sample 6) demonstrated the higest moisture retention capacity (Figure 4). The ability of galactomannans, which include guar gum, to form hydrogen bonds with water molecules results in an increase in the moisture retention capacity of food systems (Mudgil et al., 2014). This effect corroborates the hypothesis that polysaccharide macromolecules can be integrated into the protein matrix to form a compact spatial network capable of retaining moisture over an extended period. This assertion is also supported by the findings of Seo (2022).

In the control sample and sample 1 (baked sour cream), pronounced syneresis is observed, which can be explained by the increased content of free water. This is confirmed by the high value of water activity and the substantial thermal denaturation of proteins in sample 1, resulting in a partial loss of their moisture-binding capacity during cream simmering. The results obtained for sample 5, which contained β-glucan, demonstrated that this polysaccharide was incompatible with fermented cream, as evidenced by the degree of syneresis. Therefore, the efficacy of utilizing milk protein concentrates in sour cream with a fat content of 10%, including in conjunction with galactomannan (guar gum), has been substantiated.

Further research should be conducted to elucidate the mechanism of β-glucan structuring and moisture-binding action in sour cream.

Conclusions

1. The use of whey protein concentrate, obtained by ultrafiltration, and hydrolyzed concentrate of demineralized whey concentrate, in amounts providing a protein content of 3.38% and 3.22%, respectively, in sour cream with a fat content of 10%, results in the formation of technologically active ingredients that serve to improve the rheological characteristics, as well as the moisture retention capacity, of the finished product.
2. Prolonged high-temperature treatment of cream before fermentation (95–98 °C, 3 h) due to thermal denaturation of whey proteins has been observed to significantly reduce the physicochemical and viscosity characteristics of sour cream with a fat content of 10%.
3. The presence of monosaccharides in sour cream has been observed to exert a slight reduction in the functional and technological properties of protein concentrates, with the greatest impact observed with regard to water activity.
4. The addition of polysaccharides at a concentration of 0.5% has been observed to exert a varying degree of influence on the technological properties of whey protein concentrate at a concentration of 1% in sour cream. The incorporation of guar gum has been demonstrated to enhance the rheological characteristics of sour cream, including its thixotropic ability, and to effectively prevent syneresis during storage. Conversely, the use of β-glucan derived from oats has been found to exhibit limited compatibility with sour cream, as evidenced by an anomalous deterioration in the rheological and physicochemical characteristics of the product, necessitating further investigation.

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