Effects of protein and carbohydrate ingredients on colour of baked milk products

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Abstract

Introduction. The aim of the present research was to study the influence of the presence of protein and carbohydrate ingredients on intensity of the Maillard reaction in baked dairy products and their color.

Materials and methods. Cream with a fat content of 10%, as well as creams with the addition of whey protein, hydrolysed whey concentrates, and glucose-fructose syrup served as objects of study. The color characteristics of the baked milk cream were examined by the CIE Lab system using a digital colorimeter; the active acidity was determined by the potentiometric method, and the overall sensory quality was estimated by the weighted average of the scores.

Results and discussion. In the CIE Lab system, only the coordinates “a” and “b” should be used to characterize the color change of milk of 2.5% fat and cream of 10% fat during heat treatment at 95–97 ºC for 160–180 min, as the L indicator (light level) is not sufficiently informative. According to the selected coordinates, rational ranges were established as a criterion for the completeness of the Maillard reaction for baked milk and cream, in particular for coordinate “a” in the range from 1.5 to 2.0 units, for coordinate “b” from 11.5 to 13.0 units.

The application of whey protein concentrate, hydrolysed demineralized whey concentrate, and glucose-fructose syrup, which contain monosaccharides and proteins, significantly enhanced the Maillard reaction. The recommended values for color coordinates of cream with milk protein and carbohydrate ingredients were achieved during the simmering process. For cream with whey protein concentrate, this occurs at a minimum of 21 min; for cream with hydrolysed whey concentrate at a minimum of 28 min, and for cream with glucose-fructose syrup and whey protein concentrate at a minimum of 18 min. The samples with whey protein concentrate and glucose-fructose syrup, including those one with whey protein concentrate, showed an excellent level of quality in terms of sensory characteristics after 20 min, while the sample with hydrolysed whey concentrate demonstrated this after 30 min of simmering. These results correlated with the rational duration of cream simmering to achieve the recommended degree of color. A slight decrease in acidity was observed in all cream samples during the heating process. The reduction in the duration of the simmering process of dairy products with simultaneous achievement of recommended color characteristics will contribute to a significant reduction in heat energy consumption.

Conclusions. The duration to achieve desirable color characteristics of baked milk cream can be reduced by the inclusion of ingredients containing carbohydrates and proteins such as glucose-fructose syrup, whey protein concentrate, and hydrolysed demineralized whey concentrate.

Introduction

Baked milk products have an attractive creamy-brown color. Prolonged high-temperature processing at 95-99 ºC causes the Maillard reaction in milk and cream with the formation of melanoidins, while whey proteins become denatured (Lohinova et al., 2023; Nielsen et al., 2022; Zheng, 2023), fat globule membranes are destroyed, and lipids are partially degraded with the formation of aromatic compounds (Jo et al., 2018).

Long-term heat treatment of milk can result in the formation of compounds harmful to human health, such as carboxymethyl lysine and acrylamide (Tamanna et al., 2015). Therefore, the process of milk and cream simmering should be stopped immediately after achieving the desired technological effect, primarily in terms of color characteristics. At the same time, there is currently no method for objective control of the color characteristics of dairy food systems, including cream one.

Information on heat treatment conditions is specified for high- and medium-fat cream only (Newton et al., 2012). Meanwhile, there is a growing demand for fermented cream products with reduced fat content up to 10% (Gouel et al., 2019). Milk whey, by-product from the dairy industry, is widely used in the food industry for the enrichment of various products (Kochubei-Lytvynenko et al., 2022, 2023). Sour cream obtained from low-fat cream has a liquid consistency (Shepard et al., 2013), and thus, the authors propose the addition of whey protein concentrate and liquid hydrolyzed concentrate of demineralized whey to its composition (Mykhalevych et al., 2022). Furthermore, it is possible to improve the sensory characteristics of sour cream with milk protein concentrates by preliminary cream simmering (Wang et al., 2022), since the lactoglobulins and monosaccharides in whey protein concentrate and liquid hydrolysed concentrate of demineralized whey are able to activate the Maillard reaction (Brands et al., 2001; Li et al., 2022).

However, excessive heating of milk and cream can lead to reduction in protein nutritional value and the formation of undesirable compounds (Choudhary et al., 2013, Li et al., 2021). Therefore, strict control of the color, taste, and odour characteristic of baked dairy products is required.

Color changes in heat-treated milk were determined using color difference (ΔE) and yellowness index (YI), which were chosen as the simplest and most reproducible characteristics (Pagliarini et al., 2006), although other alternative methods exist.

There is currently no complete description of the methodology for determining the color of milk and dairy products that would ensure repeatability and comparison of research results (Milovanovic et al., 2020). The authors revealed that among a number of dairy products studied in the CIELab color space (lowercase letters), the color variability for sour cream was the lowest.

Three attributes were used to objectively determine the color of dairy products: hue, brightness, and chroma in the instrumental color spaces CIELab, CIELu*v* and CIEXYZ (Leon et al., 2006). Currently, Hunter Lab and CIELab color spaces are most widely used to analyse colorimetric information, where L* defines the perception of light and dark, a* defines red or green, and b* defines yellow or blue (Pathare et al., 2012; Rossel et al., 2006). The CIELab color space will be used to study the color characteristics of cream as a basis for the production of baked sour cream.

Based on the results of the conducted study, recommendations will be developed for the industry to accelerate the technological process of cream simmering and correspondingly reduce energy consumption, including through the use of protein concentrates and carbohydrate-containing ingredients.

In light of the above, the aim of this study was to examine the patterns of color change in cream during the production of sour cream, with a particular focus on the impact of milk protein and carbohydrate-containing ingredients during the simmering process.

To achieve this goal, the following tasks were formulated: (a) to determine the recommended ranges of color characteristics as a criterion for the completeness of heat treatment of baked milk product, based on the results of the analysis of changes in the nature and degree of color of milk with 2.5% fat and cream with 10% fat during the simmering process; (b) to study the rational simmering duration of cream with 10% fat, enriched with milk protein concentrates and carbohydrate-containing ingredients, according to the specified criteria, to achieve the recommended values of color characteristics; (c) to study the dynamics of changes in acidity and sensory characteristics of cream during the simmering process to compare the identified patterns with the nature of the formation of color characteristics; (d) to formulate conclusions about the influence of individual components on the simmering process.

Materials and methods

Materials

The main raw materials chosen for simmering was cream with a fat content of 10% and milk with a fat content of 2.5.

To enrich the cream with whey proteins, the following protein-containing ingredients were used: whey protein concentrate, containing: solids – 94%, including protein – 80%, carbohydrates – 7%, fat – 7%; liquid hydrolysed concentrate of demineralized whey (Osmak et al., 2021), containing: solids – 40%, including protein – 4.4%, carbohydrates – 33.8%, fat – 0.4-0.6%, ash – 1.0-1.2%. After fermentation, the liquid hydrolysed concentrate of demineralized whey retains about 5% lactose, with the rest of the carbohydrates being monosaccharides.

It was previously determined the recommended content of the selected ingredients in cream ensuring the formation of high-quality finished products: 1% of whey protein concentrate and 30% of liquid hydrolysed concentrate of demineralized whey (Mykhalevych et al., 2022).

For study the influence of monosaccharides on the rate and completeness of the Maillard reaction, glucose-fructose syrup (GFS-42, "Intercorn Corn Processing Industry", Ukraine) was also added to the creams. The amount added syrup ensured an equivalent content of monosaccharides introduced into the cream together with the hydrolysed whey concentrate. The 40% liquid hydrolysed concentrate of demineralized whey contains 29.32% monosaccharides, so its addition to cream at a rate of 30% results in 8.8% monosaccharides in the creams. The glucose-fructose syrup contains 67.2% monosaccharides, so to ensure their equivalent content in the creams, 13.1% of this syrup was added.

Preparation of experimental samples

Milk protein concentrates were dissolved directly in cream at 40°C and holding for 30-40 minutes for preliminary swelling, after which the cream was filtered and subjected to simmering.

The simmering of creams and milk was conducted at a temperature of 96±1°C. Samples were collected at various time points during thermal treatment: 0, 30, 60, 90, 120, 150, and 180 minutes. During the simmering process, the following parameters were determined: degree of coloration, sensory properties, and acidity.

Methods

Color was determined using a digital colorimeter (Colorimeter, model LS173, Linshan, China) according to the CIE Lab system. The following parameters were assessed: L: Lightness level (from 0 for black to 100 for white); Color ranging from green (-) to red; Color ranging from blue (-) to yellow (+) (Ścibisz et al., 2019). Prior to measurement, the device was calibrated using a white standard according to the manufacturer's instructions.

The acidity was determined using the potentiometric method with a pH meter ADWA AD1030 at a temperature of 20±0.5°C (Shepard et al., 2013).

Sensory parameters including consistency, aroma, taste, colour, and appearance were assessed using a 5-point scale (1 – poor, 2 – acceptable, 3 – good, 4 – very good, and 5 – excellent). Taste assessment focused on the pasteurization flavour, sweet, and creamy tastes. Each parameter was weighted accordingly: consistency – 0.2; aroma – 0.2; taste – 0.2; color – 0.3, and appearance – 0.1.

The overall sensory quality was calculated as the weighted average of the scores. Cream samples were categorized based on the calculated overall weighted score as follows: excellent (20.0–25.0 points); good (16.0–19.9 points); satisfactory (11.0–15.9 points); practically unacceptable (6.0–10.9 points); unacceptable (less than 6 points) (Polishchuk et al., 2013).

Results and discussion

Recommended ranges of colour characteristics for baked milk products

At the first stage, the dynamics of changes in color characteristics of milk with 2.5% fat and cream with 10% fat during processing over a period of 3 hours were determined, which is the recommended duration of processing according to current technological instructions.

In the CIE Lab system, the L parameter (lightness) was not sufficiently informative for milk and cream during the 180-minute processing, so only the parameters "a" and "b" were used to characterize colour changes.

The results of measuring these parameters during the processing of milk and cream are shown in Figure 1a, b.

According to Figure 1, cream had numerical values exceeding those typical for milk for the colour coordinates "a" and "b" before processing. In particular, cream exhibited a more yellowish hue in the "b" coordinate compared to milk, which can be explained by its higher fat content with the presence of the colour compound β-carotene.

With the onset of processing, the rate of color change was significantly higher in milk than in cream, which can be attributed to the higher lactose and protein content in milk as the main reactants of the Maillard reaction (Mehta 2015).

Throughout the 180-minute processing, the color intensity increased monotonically for both milk and cream across both color coordinates. A crossing of the values of both color characteristics for milk and cream was observed at the 160th minute. Based on this, ranges of color values for baked milk and baked milk cream were selected as criteria for the recommended degree of their coloration, with minimal values for both colour coordinates corresponding to the indicated intersection point in Figure 1a, b.

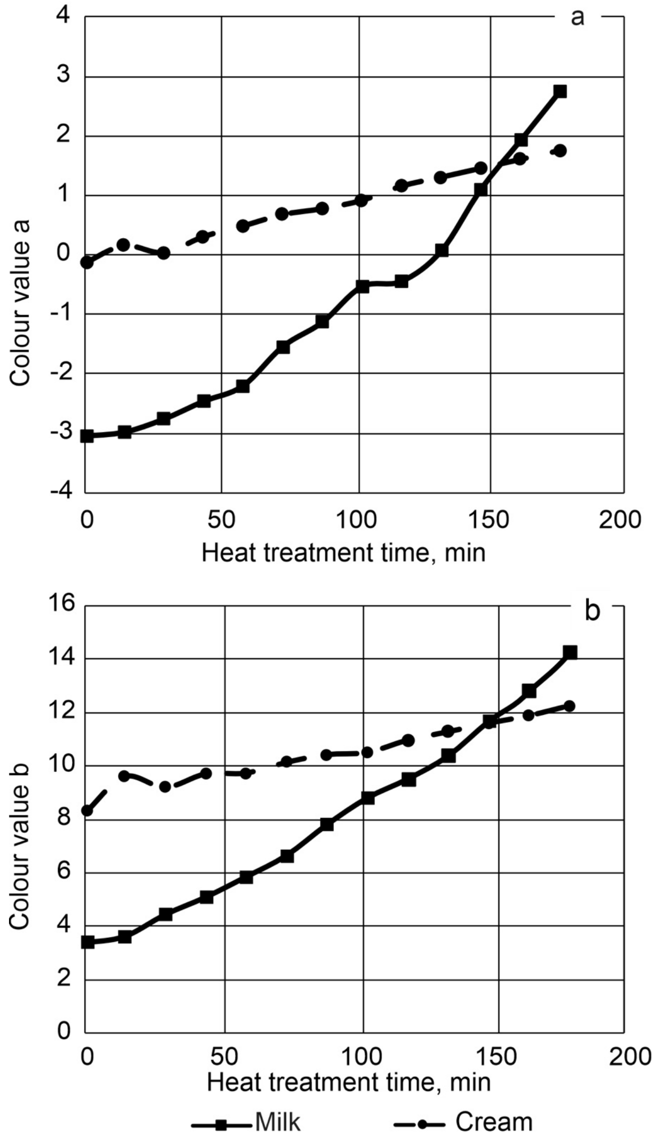

Figure 1. Dependence of changes in color coordinates on simmering time for milk and cream: a – color coordinate "a"; b – color coordinate "b"

Therefore, for the "a" coordinate, the range of values from 1.5 to 2.0 units was chosen as the criterion for achieving the appropriate degree of cream coloration resulting from the Maillard reaction, and for the "b" coordinate, the range from 11.5 to 13.0 units was chosen. If the color characteristics fall within these ranges, it is recommended to stop the cream simmering to save energy costs and prevent possible thermal destabilization of the fat emulsion (Hansen et al., 2020).

Time for cream simmering

The effects of milk-protein and carbohydrate concentrates on the change in color coordinates of 10% fat cream during simmering over 60 minutes was studied. The decision to reduce the simmering time from 180 to 60 minutes for cream with concentrates was based on existing information regarding the potential intensification of the Maillard reaction in the presence of monosaccharides and protein concentrates (Deepika et al., 2013, Spotti et al., 2019), as well as proven by the results of previous studies. The designations for the samples were as follows:

- Control sample (cream);
- Sample 1 – cream with 1% whey protein concentrate;
- Sample 2 – cream with 30% hydrolysed whey protein concentrate;
- Sample 3 – cream with 13.1% glucose-fructose syrup;
- Sample 4 – cream with 1% whey protein concentrate and 13.1% glucose-fructose syrup.

The change in color characteristics of these samples is presented in Figure 2.

According to Figure 2, the cream samples with whey protein concentrate (samples 1 and 4) were characterized by slightly elevated values for the color coordinate "a", which is likely due to an excess of whey proteins. Proteins and carbohydrates in the concentrates in samples 1–4, at 60 minutes of simmering, increased the value of the color coordinate "a" by 8 times (sample 1), 10 times (samples 2 and 4), and 10.4 times (sample 3), compared to the control sample. This effect can be explained by the high ability of monosaccharides and milk proteins to participate in the Maillard reaction (Leiva et al., 2016).

Regarding the color coordinate "b", compared to the control sample, the experimental samples had higher values due to the initial coloration of the added ingredients. The highest colouring of sample 2 – with whey concentrate that after lactose fermentation acquired a typical yellowish-cream shade – is worth noting. Despite the somewhat different nature of the colour change during simmering, at the 60th minute of this process, all investigated samples with protein and carbohydrate ingredients were characterized by fairly close values. However, the presence of monosaccharides as highly reactive compounds (Brands et al., 2001) in samples 3 and 4 allowed to achieve the most intense colouring.

Through the analysis of the research results and comparing their values with the recommended ranges for coordinate "a" from 1.5 to 2.0 units, and for coordinate "b" from 11.5 to 13.0 units determined in the first stage of the study, the recommended simmering duration for cream with protein and carbohydrate ingredients, as shown in Table 1, was found.

Table 1

Time of the cream simmering with protein and carbohydrate ingredients

Colour values CIELab	Time to achieve color coordinate values for samples, min			
	Sample 1	Sample 2	Sample 3	Sample 4
a	21	28	18	18
b	20	–	12	5

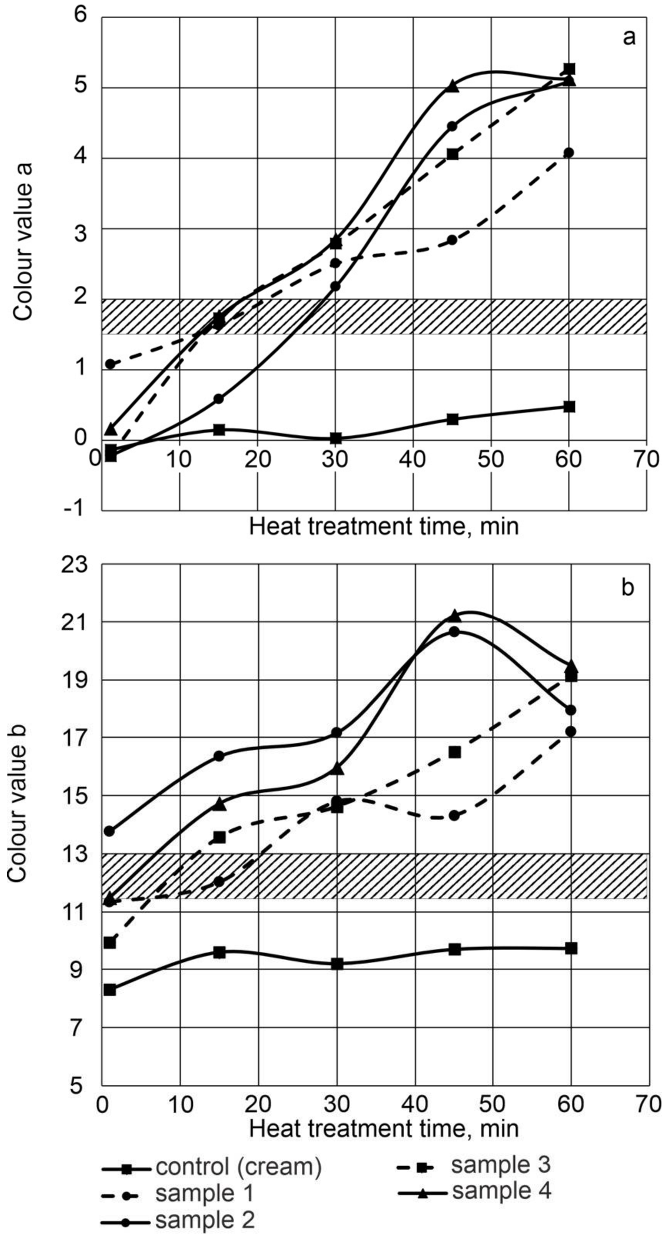

Figure 2. Dependence of color coordinates on simmering time for cream with protein and carbohydrate ingredients

According to Table 1, achieving the recommended degree of coloration using the established standard during the simmering process of 10% fat cream with carbohydrate and protein ingredients was significantly reduced compared to cream without Maillard reaction-activating additives.

For sample 2 achieving coloration based on the colour coordinate "b" occurred immediately after adding the hydrolysed whey concentrate to the cream, which was characterized by intense coloration. The rapid change in color of hydrolysed dairy products and concentrates due to the accumulation of lactose hydrolysis products is also noted by other researchers (Pinto et al., 2021). At the same time, to achieve the recommended degree and type of coloration based on the color coordinate "a", this sample requires the longest simmering time compared to other samples.

If we consider the minimal simmering time for creams to achieve the recommended values of both color coordinates, then for:

- Sample 1, this indicator should be no less than 21 minutes;
- Sample 2, no less than 28 minutes;
- Samples 3 and 4, no less than 18 minutes.

Thus, the simmering time for creams with whey protein concentrate is reduced by 7.6 times, with hydrolysed whey protein concentrate is reduced by 5.7 times, with glucose-fructose syrup, including in combination with whey protein concentrate, is reduced by 8.9 times compared to the control sample. Therefore, the possibility of significantly accelerating the simmering process of cream by introducing protein and carbohydrate concentrates into their composition has been proven. Concentrates containing monosaccharides such as glucose and fructose in glucose-fructose syrup exhibit high reactivity. The exceptional role of monosaccharides in accelerating the Maillard reaction is also confirmed by research results (Zhang et al., 2019).

Acidity and sensory characteristics of cream during simmering

Sensory indicators of the control and experimental samples of clotted creams with protein and carbohydrate components were studied before and during the first 40 minutes of simmering, which does not exceed the recommended simmering duration for all samples. The overall weighted score obtained from the results of the sensory quality assessment of the samples is presented in Figure 3.

According to Figure 3, an excellent quality level (above 20 points) was achieved for samples 1, 3, and 4 after 20 minutes, and for sample 2 after 30 minutes of heating, which correlates well with the recommendations for the rational duration of simmering to achieve the recommended colour characteristics. As for the control sample, it is understandable that the duration of thermal processing for 40 minutes is insufficient to form its excellent quality not only in terms of colour characteristics but also in terms of taste, smell, and consistency.

The acidity of the cream samples during the simmering process was also determined. The research results are presented in Table 2.

According to Table 2, the acidity of cream with milk-protein concentrates is slightly lower, which can be explained by additional binding of free water. Samples 3 and 4 are characterized by lower acidity, attributed to the acidic nature of the glucose-fructose syrup resulting from the acidification of the reaction environment during its production (Xu et al., 2016).

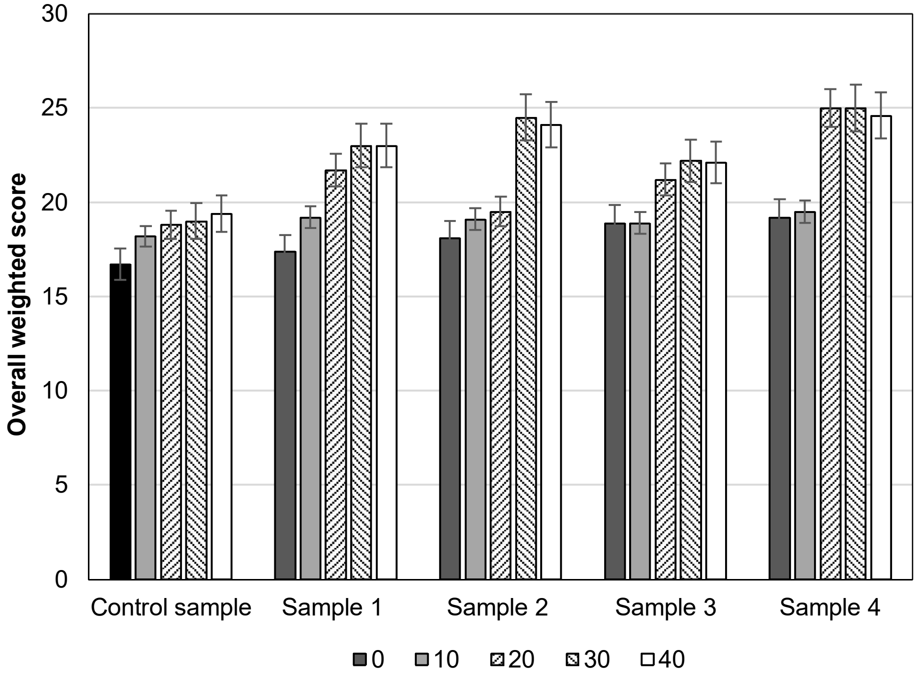

Figure 3. Overall weighted score of sensory evaluation of clotted cream samples

Table 2

Acidity of cream (pH) at different simmering time

Samples	pH of cream at the simmering time, min				
	0	10	20	30	40
Control	6.67±0.19	6.60±0.17	6.59±0.17	6.57±0.11	6.55±0.15
Sample 1	6.65±0.17	6.55±0.15	6.49±0.15	6.42±0.16	6.35±0.13
Sample 2	6.64±0.15	6.38±0.12	6.30±0.12	6.26±0.10	6.21±0.15
Sample 3	6.14±0.16	6.10±0.15	6.08±0.14	6.04±0.15	6.00±0.12
Sample 4	6.12±0.11	6.08±0.12	6.05±0.13	6.01±0.11	5.98±0.11

During heat treatment, there is a slight decrease in the acidity of all samples. Despite the loss of carbon dioxide, cream exhibit processes where soluble calcium and phosphorus transition into insoluble calcium phosphate with the release of acidic phosphates. Sample 2 demonstrates the most dynamic decrease in pH due to the increased content of mineral compounds. The increase in pH levels after prolonged heating of milk, according to data (Jasim, 2014), was not observed in the investigated samples of cream due to their different fat content. Thus, significant changes in the acidity of creams with milk-protein concentrates during simmering were not noticed. Glucose-fructose syrup significantly reduces the acidity of samples at the beginning of heat treatment but without significant changes during simmering.

The decrease in the acidity of cream and the likely change in the structure of protein macromolecules after prolonged heat treatment (Krishna et al., 2021; Li et al., 2021) may affect the microstructure of the protein gel in baked sour cream, which requires further investigation.

Conclusions

1. Recommended color criteria for baked milk and clotted cream in the CIE Lab system are as follows: for coordinate "a" from 1.5 to 2.0 units; for coordinate "b" from 11.5 to 13.0 units. After achieving colour characteristics within these ranges, the process of simmering dairy products can be stopped to reduce energy consumption. The dynamics of colour changes during heat treatment are higher in milk than in cream due to the higher content of highly reactive components.
2. To achieve the recommended colour coordinate values, the simmering process for cream with milk-protein and carbohydrate ingredients should last as follows: for cream with whey protein concentrate – no less than 21 min; for creams with hydrolysed whey protein concentrate – no less than 28 min; for creams with glucose-fructose syrup, including in combination with whey protein concentrate – no less than 18 min. Concentrates containing monosaccharides such as glucose and fructose demonstrate the highest technological efficiency.
3. Excellent quality level for samples with whey protein concentrate, glucose-fructose syrup, and their combination is achieved after 20 min, while for the sample with hydrolysed whey protein concentrate, it's achieved after 30 minutes of simmering, which correlates with recommendations for the optimal simmering duration to achieve the recommended degree of coloration. A slight decrease in the acidity of all cream samples occurs during simmering. The application of glucose-fructose syrup during heat treatment has the greatest impact on acidity due to the increased acidity of this syrup.
4. Further research prospects include studying the color characteristics of fermented clotted cream, including during storage, as well as investigating the microstructure of baked sour cream with milk-protein concentrates and glucose-fructose syrup.

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