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Received: October 2018 – Accepted: January 2019

Development of a reduced fat and lactose-free dairy spread containing viable lactic acid bacteria – Part 1: Technology of manufacture

Keywords: butter product, buttercream, cream, homogenization, lactose-free, functional dairy product, product development.

SUMMARY

The popularity of buttercream, considered to be a reduced energy, cheaper version of butter with a better function of use, has been constant in Hungary for three and a half decades. Our objective was to develop a new type of functional buttercream manufacturing technology. In order to achieve this, the pressure value resulting in parameters ensuring the adequate texture and good adsorption of the finished product during the one-stage homogenization of 30% fat cream was determined, as well as to what extent the viscosity of cream and its ease of handling are affected by homogenization. It has been found that the criteria for the homogenization effect can be achieved by single homogenization of a 30% fat cream containing a milk protein concentrate serving as the raw material for the new type of butter product on a single-stage homogenization machine at 65 °C and 15 MPa (150 bar). Due to the increased viscosity of the cream treated this way, the use of a tubular or scraped-surface heat exchanger is recommended. Our reduced fat, lactose-free buttercream with live culture can be manufactured safely with the technology developed, and with the enzyme and starter cultures used, the lactose content of the product will be less than 0.1%.

Introduction

Butter products containing 25 to 45% fat are usually post-heat-treated fat-in-water type emulsions, which are considered to be cheaper, easier to use and reduced energy versions of butter. In their domestic development, the work of the employees of the Pécs division of the Hungarian Dairy Research Institute (MTKI) has been essential. Already in the 1970s, the product development possibilities of homogenization were recognized and intensive research into the effect of homogenization on emulsion was launched. During this, the average fat globule diameters ($\bar{d}$) belonging to the optimal homogenization pressure and temperature of the different dairy products were determined, the index for cluster formation (k-value) was introduced, and the methods for measuring homogenization efficiency were developed (centrifugation and turbidimetric spectrophotometric procedures). Methods were standardized and then introduced into industrial practice **[4, 8, 9]**.

Those groundbreaking research efforts helped the researchers of MTKI to develop, by 1983, the Party buttercreams, considered to be functional from a number of points of view and still one of the successful products of the Hungarian dairy industry. In the 20 years following the introduction of the product in 1984, the total volume of production reached 150,000 tons **[9]**, while the domestic consumption of milk and dairy products has been decreasing. The fresh, clean, aromatic, butter-like taste and the convenience feature of a spreadable texture that does not considerably soften at room temperature play a decisive role in the undiminished popularity of buttercream, which still holds a leading position among spreadable butter

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products. Critical elements of its production are the double homogenization (first during pasteurization at 65–70 °C and a pressure of 3–5 MPa, and then at 20–22 °C and a pressure of 20–25 MPa, following the inoculation with pure lactic acid bacterial culture) resulting in an average fat globule diameter of less than 0.5 µm (absorption) and a cluster formation index of k = 2.0–2.5 (texture strength, emulsion stability, syneresis inhibition), and the application of a stabilizing agent ensuring the perfect emulsification of the added free butter fat and the protection of the proteins during heat treatment **[5]**.

Unfortunately, the nutrition physiology benefits of milk and dairy products, including buttercream, are not freely available to everyone, as some people have to limit or completely cut the consumption of foods containing lactose, due to the decreased activity or partial or total lack of the lactase enzyme (the so-called lactose intolerance) **[2, 13]**. Adult lactose intolerance is a genetically determined sensitivity. The allele responsible for breaking down lactose can only be found in roughly one third of the adult population of Earth, while the body of the majority of people (70-75%) is unable to utilize lactose **[3]**. However, the territorial distribution of data shows immense inequalities because it is linked to the importance of milk production and milk processing in the lives of the different peoples over the past millennia **[11, 12]**. Among the Hungarian adult population, the ratio of lactose intolerant individuals is 37–39% **[1, 6, 7]**. Nevertheless, it should be noted that adult lactose intolerance is not a disease but a completely normal physiological condition **[10]**, because the gene responsible for the production of the lactase enzyme is naturally deactivated within 3 to 5 years after weaning.

In Europe and North America, the most successful and most dynamically developing product range in recent years have been that of lactose-free dairy products, because some consumers are willing to buy lactose-free foods that often cost twice as much as conventional products, and so their production is always profitable. In Hungary, Naszálytej was the first to produce lactose-free dairy products in Vác, in 1995. The range which contained only lactose-free milk in the beginning has expanded significantly. Other domestic manufacturers have only appeared in this market segment only much later, in the 2010s.

The objective of our work was (1) to develop the production technology of a new type of functional dairy product, reduced-fat, lactose-free buttercream with live culture, (2) then compare our new butter product with commercially available buttercreams using instrumental texture analysis, and (3) finally assess the expected reaction of the market to our experimental product. In the first part of our two-part article, the process of realizing objective no. 1 is presented.

Materials and methods

Raw materials and additives

The composition of the cream and skim milk (Naszálytej, Vác) used for testing the effect of homogenization and to produce the finished product is shown in ***Table 1***.

The Promikoll VK-12 NT stabilizer necessary for the production of lactose-free buttercream with live culture was purchased from Globál-Vép Kft. (Drégelypalánk), while the MPC 80 milk protein concentrate with a dry matter content of 95.00% and protein content of 80.40% was obtained from Sole-MiZo Zrt. (Csorna). Purified liquid enzyme Maxilact LX5000 (DSM, Heerlen, the Netherlands) from *Kluyveromyces lactis* yeast was used for the decomposition of lactose and for the manufacture of the product a FD-DVS XT-312 mesophilic, LD-type, heterofermentative lactic acid bacterial culture (Chr. Hansen, Hørsholm, Denmark) was also used.

Instruments

The chemical composition of the raw materials was determined on milk and cream channels developed in calibration models programed into a regularly calibrated LactoScope FTIR Advanced automatic milk and dairy product analyzer (Delta, Drachten, Hollandia).

To weigh the materials, a PS-510/C/1 digital precision scales (Radwag, Radom, Poland) and an EW 3000-2M scales (Kern, Balingen, Germany) were used.

For pH measurement, a Portamess 911 X pH (Knick, Berlin, Germany) pH meter with a pH/PT 1000 combined electrode with a temperature detector was used. Calibrations before the measurements were carried out using InLab buffer solutions (pH 4.01 and pH 7.00, Mettler-Toledo, Schwerzenbach, Switzerland).

To disperse powders and to homogenize the raw materials, a WiseStir HT-50AX laboratory stirrer (Daihan, Seoul, Korea) was used.

Heat treatments were performed on an LBM-2/3 A, 15 L tempered laboratory water bath (Labomark, Mosonmagyaróvár).

For the homogenization of the samples, a Homolab 2 laboratory homogenizer (FBF Italia, Sala Baganza, Italy) with a digital manometer and a capacity of 10 L/h with a maximum pressure of 150 MPa was used.

Temperature values were determined using a regularly calibrated liquid-filled (mercury) laboratory thermometer.

The viscosity of the creams was measured with an RVT-DV II digital viscometer (Brookfield, Middleboro, MA, USA) at 25 °C for 30 seconds, readings were recorded at 30 seconds. For the viscosity measurements, 600 ml low form beakers were used, and for the heat treatments 1,000 ml low form and 2,000 ml high form Simax beakers were used (Avesz, Pécs).

Samples were filled into thermoformed jars (Csőkeplast, Kocsér) with sealable top foil, and were sealed using the welding head of a UC-6 laboratory cutter (Bernador, Inárcs).

Fat globules and their clusters were visually displayed using a light microscope (Traveler SU 1070; Foto-Elektronik-Vertriebs, Kaiserslautern, Germany) equipped with a digital eyepiece and connected to a computer.

Methods

Determining the optimum of homogenization pressure

The adequate texture of buttercream and its good absorption mainly depend on the homogenization pressure applied, and the fat globule diameter ($\bar{d}$ < 0.5 µm) and k-value (2.0–2.5) resulting from it. Thus, our analyses were aimed to determine the pressure at which these parameters can be achieved during the single-stage homogenization of a 30% fat cream.

The 1.00% MPC 80 milk protein concentrate, weighed on the PS-510/C/1 digital precisions scales, was dispersed in the skim milk used to adjust the fat content of cream with a fat content of 40.20%, weighed on the EW 3000-2M digital precision scales, to 30.00% was dispersed using the WiseStir HT-50AX overhead laboratory stirrer. The skimmed milk enriched with the milk protein concentrate was added to the calculated amount of cream and the mixture was homogenized using the WiseStir HT-50AX overhead laboratory stirrer. 3000 g of the enriched cream raw material with the adjusted fat content was heated to 65 °C on the LBM-2/3 A laboratory water bath and a sample of 500 ml was taken. The remainder was homogenized at pressures of 5, 10, 15 MPa using a Homolab 2 laboratory homogenizer, while taking samples of 500 ml at all three pressures, making sure that the cream portion belonging to the given pressure is sampled in each case. This was achieved by collecting approximately 200 ml of cream in a collection vessel after each pressure change, and the samples were only taken following this. Homogenization efficiency was investigated according to standard MSZ 12047-1984 **[4]**, the scheme of which is illustrated in ***Figure 1***.

Determining the viscosity of 30% fat cream enriched with milk protein concentrate

Protein enriched fat with a 30% fat content was prepared as described above. Following homogenization, 500 ml samples in 600 ml beakers were cooled to 25 °C, and their viscosity was determined using an RVT-DV II digital viscometer at 25 °C, with a special probe corresponding to the measurement range at 100/min rpm. The value displayed on the digital display of the instrument was always recorded 30 seconds after the start of the measurement. The measurements were performed in triplicate.

Results and evaluation

Determining the optimum of homogenization pressure

Our basic goal was to increase the nutrition physiology benefits of classic buttercream **[5]** during the development of the new product. As was mentioned above, one of the most important of these is the almost complete corpuscular fat absorption resulting from the presence of fat globules with an average diameter of less than 0.5 µm, adsorbing appropriate protein amounts **[9]**. At this stage of our work, therefore, we wanted to clarify whether the desired average fat globule diameter ($\bar{d}$) and cluster formation index (k-value) can be achieved by a one-time, single-stage, warm homogenization, which can only be attained in the case of traditional buttercream with a two-time, single-stage homogenization at a lower pressure (5 MPa) at higher and higher pressures (20-30 MPa) at lower temperatures. The values one of the components required for the calculation of the k-value at a later time, the Z_2 creaming index measured in aqueous dilutions are shown in ***Table 2***, while ***Figure 2*** will provide assistance in the interpretation of the results.

According to ***Figure 2***, the relationship between the homogenization pressure and the Z_2 creaming index can be described by a quadratic polynomial. The moment of cluster formation is represented by the minimum value of the curve, which can be calculated from the equation of the fit ($y = 0.000986x^2 - 0.1369x + 8.545$):

$$Z_{2\,min} = \frac{4 \times 0{,}000986 \times 8{,}545 - 0{,}1369^2}{4 \times 0{,}000986} = 3{,}79$$

The corresponding homogenization pressure is:

$$X = -\frac{-0{,}1369}{2 \times 0{,}000986} = 69{,}4\ bar$$

These two values are shown in ***Figure 2*** by the red number and the dashed line. The left side of the curve indicates the breakdown of fat globules and the decrease of the Z_2 creaming index with the increase of the homogenization pressure. During this phase, sufficient amounts of lipid membrane material and protein are available in the plasma for fat globules to form new membranes on their surface, so that they can be present in the system as individual fat globules. On the right side of ***Figure 2*** it can be observed that by further increasing the homogenization pressure, as a result of the breakdown of the fat globules, and the consequent increase in their surface area, the system no longer contains enough membrane material and protein for the membrane formation of the individual fat globules, thus, the same protein portion is adsorbed by several globules, they become linked and clusters are formed. They are then capable of creaming, the same way as the individual fat globules corresponding to their volume and weight **[14]**. In our case, the cluster formation process starts at a pressure of roughly 7 MPa, so this value can be called the critical homogenization pressure for the product.

Values of the other component of the k-value, the Z_1 creaming index obtained during EDTA dilution are shown in ***Table 3*** and on ***Figure 3***.

Figure 3 clearly shows that the left side of the curve runs almost parallel to the left side of the curve of the Z_2 creaming index obtained for the aqueous dilution. This is natural and, at the same time, shows that the analytical method has been performed correctly, because this is the stage during which the size of the fat globules is reduced. Given that the clusters are disrupted by the protein dissolution agent (EDTA), unlike in the case of the aqueous dilution, the right side of the curve shown in ***Figure 2*** cannot be observed here. The red dashed line parallel to the ordinate indicates the previously seen 6,94 MPa pressure.

In the knowledge of the creaming indices (Z_1, Z_2) the average fat globule diameters ($\bar{d}$) and cluster formation indicators (k-values) corresponding to the different homogenization pressure values were determined (***Table 4***) using the following formulas:

$$k = \frac{Z_2}{Z_1}$$

and

$$\bar{d} = \frac{Z_1 - 0{,}11}{2{,}37}$$

The results shown in ***Table 4*** reveal that the expectations regarding the average fat globule diameter and cluster formation index for the 30.00% fat cream enriched with MPC 80 milk protein concentrate, serving as the raw material for our lactose-free buttercream with live culture can be met at a pressure of 15 MPa (at a temperature of 65 °C) with the homogenization machine used in the experiment. Although the k-value of 8.85 cannot be called extreme, however, it would be worthwhile to examine later why it is four times higher than the value reported in the technical documentation of MTKI **[5]**.

In order to confirm the results, the samples were also examined by a light microscope equipped with a digital eyepiece (***Figure 4***).

Figure 4 clearly shows the individual fat globules of unhomogenized cream with a heterogeneous size distribution (A). At a pressure of 5 MPa, the average diameter of the fat globules dropped significantly, while their number increased and their size distribution became more homogeneous (B). Increasing the homogenization pressure further reduced the average diameter of the fat globules. At a pressure of 10 MPa, cluster formation has already begun (C), and this process has progressed significantly at 15 MPa (D).

Examination of the viscosity of 30% fat cream enriched with milk protein concentrate

It was an essential question at which pressure the viscosity of cream begins to increase intensively, and how easy it would be to handle, on an industrial scale, the cream at the pressure of 15 MPa described in the previous subsection, where $\bar{d}$ = 0.44 µm and k = 8.85, during transportation (pump type) and pasteurization (plate cream pasteurizer or tubular heat exchanger). Results are shown in ***Figure 5***.

As a result of increasing the homogenization pressure from 0 to 5 MPa, the viscosity value nearly tripled, while between 5 and 15 MPa there was a huge, approximately 16-fold increase (***Figure 5***), presumably due to the clusters that formed in the system. There was a close correlation between the homogenization pressure and viscosity (R^2 = 0.971). The equation of the exponential curve fitted to the measurement points is $y = 33.5285 \times e^{0.0255792x}$. Based on this, the viscosity value corresponding to the critical homogenization pressure of 6.94 MPa is 203.0187 mPa·s. Thus, at the moment of cluster formation, the viscosity is 203 mPa·s (cP), indicated in ***Figure 5*** by a red number and a dashed line. This is consistent with what was described by Walstra et al. **[14]**, according to which, depending on the protein content of the system, there is a significant increase in viscosity already at a pressure of 7 MPa, while the increase at 21 MPa is more than 30-fold. The high viscosity value at 15 MPa also made it clear that industrial scale heat treatment should not be tried using a traditional cream pasteurizer, but cream can be safely pasteurized using a tubular or scraped-surface heat exchanger.

Production of reduced fat (30%), lactose-free buttercream with live culture (manufacturing technology)

For the development of the manufacturing process, first the recipe for the product was created (***Table 5***). In terms of fat content, our objective was to achieve a reduction of at least 20% compared to traditional buttercream considered as the control product, so it was determined at 30%. The protein required for the successful cluster formation of homogenization was introduced as milk protein concentrate MPC 80 instead of skim milk powder, which inevitably would have led to an increase in sweetness during lactose decomposition.

The lactase enzyme concentration and the temperature used were set according to the publication of Fenyvessy et al. **[2]**, while the amount of mesophilic lactic acid bacterial culture was chosen in accordance with the recommendation of the manufacturer (Chr. Hansen). When creating the stabilizer, the basic principle was that it should contain the proper amount of milk protein (homogenization, viscosity) and the hydrocolloids required for texture formation and the inhibition of syneresis at the recommended concentration on the one hand, and it should be a one-component substance to facilitate the logistical tasks of manufacturers in the future.

The stabilizing agent Promikoll VK-12 NT weighed on the PS-510/C/1 digital precision scales and mixed with the necessary amount of table salt was added to the calculated amount of skim milk weighed on the EW 3000-2M digital precision scales, and it was dispersed using the WiseStir HT-50AX laboratory stirrer to form a smooth mixture, which was then added to the cream weighed on the EW 3000-2M digital precision scales. The pH value (6.60) was checked with a Portamess 911 X pH meter. The raw material was heated to 52 °C on an LBM-2/3 laboratory water bath with constant stirring, and the milk protein in the additive was rehydrated at this temperature for 20 minutes. Following this, the raw materials were further heated to 65 °C and they were homogenized at a pressure of 15 MPa using a Homolab 2 laboratory homogenizer.

The homogenized raw material was heated to 95 °C on a water bath, then it was cooled to 38 °C. Then 0.035% Maxilact LX5000 enzyme was added, and the mixture was incubated at this temperature for 60 minutes, checking the temperature every 10 minutes with a laboratory thermometer. After 1 hour, the cream raw material was cooled to 26 °C and it was inoculated with 0.015% FD-DVS XT-312 mesophilic lactic acid bacterial culture, the latter being uniformly distributed over 15 minutes by stirring. The semi-finished product was filled into thermoformed 180 ml jars with sealable top foil, similar to the packaging of most of the commercially available buttercreams, and the jars were sealed using the welding head of a UC-6 laboratory cutter. They were incubated at 25 °C for 18 hours, checking the pH every hour after 15 hours using a Portamess 911 X pH meter. At pH 4.57 the product was placed in a refrigerator and was matured at a temperature below 6 °C for 24 hours. Further refrigerated storage was carried out at the same temperature (<6 °C). The composition of the product developed is shown in ***Table 6***.

Conclusions

The relevant criteria for the homogenization of our reduced fat, lactose free buttercream with live culture can be achieved by the one-time, single-stage homogenization of a 30.00% fat cream containing 1.00% milk protein concentrate serving as the raw material for the product on a single-stage homogenization machine at 65 °C and a pressure of 15 MPa, ensuring good absorption of the buttercream in the human body. Above a homogenization pressure of 7 MPa, clusters are formed in the matrix and the viscosity of cream increases exponentially as a function of the pressure. Of course, this threshold value (7 MPa) applies only to the homogenization instrument used by us and its current technical condition. The high viscosity (1,500 mPa·s) of the cream homogenized at a pressure of 15 MPa does not allow for the safe pasteurization using a plate pasteurizer, therefore, the use of a tubular or scraped-surface heat exchanger is recommended for pasteurization. The new type of functional buttercream can be manufactured safely using the technology developed: with the enzyme (0.035% Maxilact LX5000) and starter culture (0.015% FD-DVS XT-312) concentrations used the lactose content of the product can be reduced to levels below 0.10%.

Acknowledgement

The authors thank the financial support of project EFOP-3.6.1-16-2016-00017.

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