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Development of a Curd Cake for Patients with Type 2 Diabetes: Influence of Replacing Sugar with Sweetener on Nutritional Value †

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Abstract: Sugar is one of the main ingredients of baked products, so reduction of sucrose negatively affects product appearance, texture, and mouthfeel. However, by replacing it with sweeteners such as sucralose, it is possible to create desserts with a low glycemic index and low calorie content. The aim of this study was to investigate the physico-chemical and nutritional properties, and sensory characteristics of sugar replaced with curd cake made using sucralose. Optimal results were obtained with replacement up to 50%, leading curd cake similar to the control products and having a high level of acceptance in sensory evaluation. A vibrational analysis using FTIR spectroscopy showed in these samples the presence of hydrogen bonds between water molecules and a dense packing of texture. The study of adsorption/desorption isotherms indicates the predominance of the mechanism of monomolecular physical adsorption with a weak interaction of adsorbent-adsorbate in samples with sugar replacement up to 50%. A further increase in the sugar substitute content increases the contribution from polymolecular adsorption and capillary water, which is reflected in the deterioration of sensory characteristics. The developed technology made it possible to obtain a curd cake with a caloric content of 14% lower than that of an analogue, which in its organoleptic characteristics and structure does not differ from the analogue product and contains 26% more protein.

Keywords: diabetes; sweetener; sucralose; curd cake; nutritional value

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1. Introduction

The rise in diabetes and obesity is the driving force behind the development of the food industry towards the development of low-calorie products by reducing sugar content. One of the ways to implement this trend is to use natural and synthetic sweeteners [1]. Substances with virtually "zero calories" and a very intense sweet taste that are used in small quantities to replace much higher amounts of sugar in products and are approved for use in the food industry include sucralose. However, in the process of optimizing such technologies, it becomes necessary to solve the problem of compensating for the negative impact on texture due to partial or complete replacement of sugar with a sweetener in the product formulation. In such cases, it is necessary to correct the texture of the final product by adding other components to the recipe [2]. Earlier in [3], a curd cake technology with partial replacement of sugar with sucralose was proposed. The problem of compensating for the negative effect on the consistency of the product with a low sugar content was solved by introducing additional amounts of cottage cheese and melange into the recipe (cottage cheese and melange were introduced to replenish the mass of removed sugar). This technique, of course, did not allow to restore the dry matter content; however, it made it possible to increase the amount of protein in the finished product. As is known, proteins (both egg white and casein proteins) are involved in protein network formation during thermosetting [4]. However, given the fact that cottage cheese and

melange contain about 70% water, significant weight loss can be predicted during heat treatment. However, the hydrophilic properties of proteins and the ability to retain moisture should also be considered.

The aim of this study was to produce high quality curd cake using different combinations from sucrose and sucralose in order to reduce the calorie content without affecting the physico-chemical characteristics and nutrition value (Figure 1).



Figure 1. A graphical scheme of study approach with appearance of the curd cake samples with the replacement of 0% (**S1**), 30% (**S2**), 50% (**S3**), 70% (**S4**), and 100% (**S5**) sugar with a sucralose.

2. Materials and Methods

2.1. Materials and Samples Preparation

The ingredients used in this study were obtained from local stores in city Kharkiv, Ukraine. Sucralose sold as SPLENDA™ was purchased from Tate & Lyle (PLC, UK). This sweetener contains maltodextrin and sucralose (the amount of sucralose is 1%).

A sample S1 as control curd cake was manufactured according to [5]. Other samples were as in [3] with partial or complete substitution of sugar for sucralose (Figure 1).

2.2. Methods

Fourier transform infrared coupled to attenuated total reflectance (ATR–FTIR) spectra of curd cake samples were obtained using Nicolet iS5 FT-IR Spectrometer with the versatile iD5 ATR Accessory (Thermo Scientific, Waltham, MA, USA) as the result of the accumulation of 32 scans with a resolution of 4 cm^{-1} in the range of 4000–600 cm^{-1}. The processing of IR spectra and calculations were performed using the Fourier transforms (FFT filter) procedure followed by deconvolution of the second derivative using the PeakFit (Seasolve, San Jose, CA, USA), Origin2019 (OriginLab, Northampton, MA, USA) and KnowItAll Informatics System 2021 Academic Edition (Join Wiley Sons Co., Hoboken, NJ, USA) software. The quality of the results obtained was assessed using mean values, standard deviations, and coefficient of variation.

Water vapor adsorption/desorption isotherms were obtained and measured at 293 K in a range of relative humidity of 0.20–0.95 with an adsorption vacuum Mac-Ben apparatus with helical spring quartz scales. The moisture of the samples was determined using a Moisture Analyzer ADGS-50 (Axis, Gdank, Poland). Specific surface area and other monolayer parameters (capacity of monolayer, constant C of the adsorbent-adsorbate interaction) of the samples according to water vapor adsorption/desorption isotherms calculated with use equation BET [6].

3. Results and Discussions

3.1. Influence of Replacing Sugar with Sweetener Organoleptic Indicators

The organoleptic analysis of the obtained samples made it possible to assert that the products based on sugar and sucralose have the same level of sweetness (Table 1).

This confirms previous studies with fewer samples [7]. However, the introduction of increased amounts of cottage cheese and melange into the cottage cheese cake recipe

does not completely solve the problem of compensating for the replacement of sugar. This technique made it possible to restore the total soluble solids of the semi-finished product for baking and increase the amount of protein in the finished product. However, the water content in these components and its significant loss during heat treatment leads to the formation of cavities in the texture. This was especially noticeable for samples S4 and S5. The sensory analysis allows us to conclude that the inexpediency of replacing more than 30–50% in the prescription composition of white crystalline sugar with sucralose.

Table 1. Organoleptic properties of curd cakes.

Indicator	S1	S2	S3	S4	S5
Form	Correct, corresponding to the form established in the recipe			Incorrect, lightly flattened	
Surface	The surface of the cupcakes with the presence of cracks and tears, which do not change the product				
Color	Dark brown	Dark brown	Brown	Light brown	Light brown
Appearance (section)	A well-baked curd cake with good porous structure			The presence of large voids	
Taste and smell	Intrinsic to this variety of cake without the foreign taste and smell				

3.2. Influence of Replacing Sugar with Sweetener on Physico-Chemical Properties

Moisture content and its state are important indicators of product quality when introducing new ingredients into product formulations. Figure 2a shows a fragment of the ATR-FTIR spectrum in the range of 3050–3600 cm^{-1} of the samples of curd paste, in the region of vibration of the OH group of water.

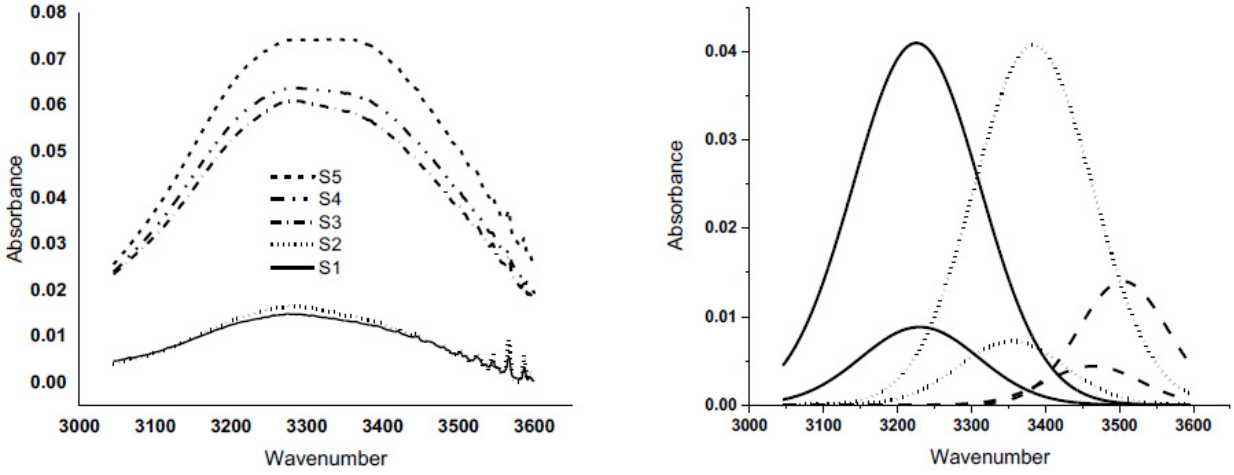

Figure 2. (**a**) Fragment of ATR-FTIR spectrum in range 3000–3600 cm^{-1} of curd cares samples; (**b**) calculated water bands G1 (solid), G2 (point), and G3 (dashed) for samples S1 and S5.

The spectrum for sample S1 has one peak at 3275 cm^{-1}. This peak is also present in the spectra of samples with sweeteners. Samples S2–S5 are characterized by the existence of a second peak at 3355 cm^{-1}. The presence of a band with peaks in the range 3275–3355 cm^{-1} indicates that the water in the product is mainly in the form of network water [8]. A shift of this band to the region of large values is observed with an increase in the concentration of the sweetener. With an increase in the concentration of the sweetener, the band becomes wider, which indicates a wider energy variability of water molecules. The shape of the band resembles a plateau with two peaks, around 3270 and 3380 cm^{-1}. With an increase in the content of the sweetener, the ratio of the intensity of these two peaks undergoes changes in the direction of increasing the intensity of the band with a higher oscillation frequency. A similar positive correlation between the position of the band of stretching vibrations of the OH group and the concentration of maltodextrin was obtained [9].

A more detailed study of this issue is possible using the approach proposed by the authors [8,10]. The essence of the approach is the possibility of studying the state of moisture in systems that simultaneously contain water and carbohydrates by analyzing a wide band of stretching vibrations of the OH group of water in IR spectra. In such systems, this band is a combination of the contributions of ordered tetrahedral H-bonded structures (G1), deformed H-bonded structures (G2), and water molecules that have free hydroxyls or small-sized associates (G3). All the above facts indicate a change in the state of hydrogen bonds of water in the food matrix of curd cake when replacing sugar with a sweetener. For a more detailed analysis of the state of moisture in the product under study, the contributions of the above water structures G1, G2, and G3 were calculated for all samples. The calculation results for samples S1 and S5 are shown in Figure 2b. Three bands were obtained for each of the states of water, which in total characterizes the band of stretching vibrations of the OH group in the range of 3050–3600 cm^{-1}. For a structure bound by strong H-bonds G1, a band was studied near 3230 cm^{-1}, for water molecules with weak or deformed H-bonds in the range 3355–3385 cm^{-1}, and for free water at 3050–3600 cm^{-1}. The position of the bands shifts towards higher vibration frequencies with increasing sweeteners content. This fact corresponds to the weakening of the hydrogen bond of water, and from the point of view of texture regarding its loose packing. The latter is confirmed by the organoleptic control of the samples (Figure 1). This change in texture density explains the greater moisture content and water activity for samples S2–S5 compared to sample S1 (Table 2).

Table 2. Physico-chemical properties of samples of curd cakes.

Property	S1	S2	S3	S4	S5
Moisture content, %	19.48	19.90	20.71	22.14	24.54
Water activity	0.903	0.930	0.949	0.969	0.989
BET specific surface area, m^2/g	165	175	153	174	126
BET monolayer capacity	2.19	2.32	2.03	2.31	1.67
Constant C	2.96	2.79	3.11	3.40	5.86

To understand the state of water in the sample, sorption isotherms were studied, which give an idea of both the amount of water and its energy state, which characterize the activity of water. According to classical concepts, this is manifested by the adsorption of mesoporous solids with capillary-condensation hysteresis with three zones of water activity. The samples have almost a similar adsorption structure, since their adsorption curves coincide in shape (Figure 3). The presence of hysteresis on the curves indicates the presence in the system, in addition to the process of physical adsorption and capillary phenomena, the process of swelling of the corresponding components and chemisorption processes. The latter is indicated by the residual amount of water at the level of 1.5–2.0% of the amount adsorbed. A detailed analysis of adsorption isotherms suggests that the largest amount of water from the total is in a hygroscopic state. This number increases in the series of samples from S1 to S5.

This difference is due to polymolecular adsorption of moisture and capillary water, while monomolecular physical adsorption predominates for the control sample. The calculated values of the constant C of the BET equation for the samples have a magnitude of 2–5, which characterizes the weak adsorbent-adsorbate interaction. As the sweetener content increases, this interaction weakens. The value of the specific surface area has a similar behavior (Table 2).

It should be noted that the data of the applied physicochemical methods are in good agreement. The change in the width and intensity of the shape of the OH-group stretching vibration band with an increase in the sugar substitute content in the samples obtained in ATR-FTIR studies positively correlates with the experimental data on sorption and water content in the samples.

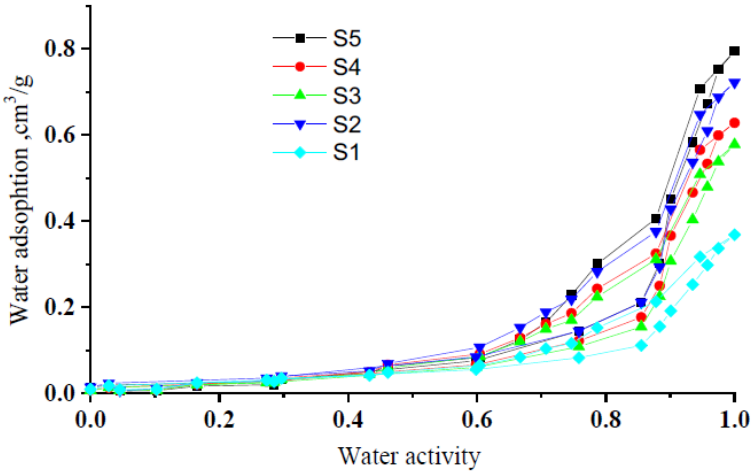

Figure 3. Isotherm water vapor adsorption/desorption of samples of curd cakes.

3.3. Influence of Replacing Sugar with Sweetener on Nutritional Value

The resulting product contains more protein, has fewer carbohydrates and fewer calories. Calculation of the energy value of samples S1, S2, and S3 based on the content of proteins, carbohydrates, and fats gives the following results 410, 386, and 369 kKal/100 g, respectively. Thus, the proposed technology makes it possible to reduce the calorie content of the product by 10–20%, depending on the replacement of sugar with a sweetener without deteriorating the nutritional value of the product.

4. Conclusions

The results of this investigation show that an encouraging novel formulation of curd cake production with a partial replacing sugar with sucralose was developed. Curd cake formulated with partial replacement of sucrose with up to 50% sweetener had organoleptic characteristics comparable with the same product prepared with 100% sucrose. When more than 50% sweetener replaced sugar in formulation, some negative sensory ratings such as poor appearance, incorrect and lightly flattened form, presence of large voids were noted. The last characteristic is confirmed by the data of the ATR-FTIR studies, which indicate the weakening of the hydrogen bond of water and the loose packing of the texture for the indicated samples. This fact is quantitatively confirmed by studies of the energy state of water by sorption/desorption isotherms. The calculation of the energy value of the obtained curd cake indicates a reduced calorie content of the product in comparison with the control sample on sugar. However, further research is needed to conduct an in vitro digestion assay to assess the possible reduction in predicted glycemic response from the developed curd cake.

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References

1. O'Brien Nabors, L. *Alternative Sweeteners*, 4th ed.; CRC Press: Boca Raton, FL, USA, 2011.
2. Clemens, R.A.; Jones, J.M.; Kern, M.; Lee, S.-Y.; Mayhew, E.J.; Slavin, J.L.; Zivanovic, S. Functionality of Sugars in Foods and Health. *Compr. Rev. Food Sci. Food Saf.* **2016**, *15*, 433–470. [CrossRef] [PubMed]
3. Aksonova, O.; Gubsky, S.; Torianik, D.; Murlykina, N. Tecnology of Curd Cake with Sucralose as Highly Effective Sweetener. *Prog. Tech. Technol. Food Prod. Enterp. Cater. Bus. Trade* **2020**, *1*, 7–20. [CrossRef]
4. van der Sman, R.G.M.; Renzetti, S. Understanding Functionality of Sucrose in Cake for Reformulation Purposes. *Crit. Rev. Food Sci. Nutr.* **2021**, *61*, 2756–2772. [CrossRef] [PubMed]
5. Pavlov, A.V. *Collection of Recipes for Flour Confectionery and Bakery Products for Public Catering Enterprises*; Gidrometeoizdat: Sankt-Petersburg, Russia, 1998.
6. International Organization for Standardization. *Determination of the Specific Surface Area of Solids by Gas Adsorption—BET Method (ISO 9277:2010(E))*; ISO: Geneva, Switzerland, 2010; 30p.
7. Aksonova, O.; Gubsky, S.; Torianik, D.; Evlash, V. The Technology of Curd Cake with Sucralose: A Infrared Spectroscopy Analysis. *BIO Web Conf.* **2021**, *30*, 01001. [CrossRef]
8. Gallina, M.E.; Sassi, P.; Paolantoni, M.; Morresi, A.; Cataliotti, R.S. Vibrational Analysis of Molecular Interactions in Aqueous Glucose Solutions. Temperature and Concentration Effects. *J. Phys. Chem. B* **2006**, *110*, 8856–8864. [CrossRef] [PubMed]
9. Sritham, E.; Gunasekaran, S. FTIR Spectroscopic Evaluation of Sucrose-Maltodextrin-Sodium Citrate Bioglass. *Food Hydrocoll.* **2017**, *70*, 371–382. [CrossRef]
10. Freda, M.; Piluso, A.; Santucci, A.; Sassi, P. Transmittance Fourier Transform Infrared Spectra of Liquid Water in the Whole Mid-Infrared Region: Temperature Dependence and Structural Analysis. *Appl. Spectrosc.* **2005**, *59*, 1155–1159. [CrossRef] [PubMed]