Physical properties of muffins sweetened with steviol glycosides as the sucrose replacement

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Received April 6, 2016
Revised July 7, 2016
Accepted September 6, 2016
Published online December 31, 2016

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pISSN 1226-7708
eISSN 2092-6456

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Abstract Overconsumption of sweets contributes to increasing obesity among children and adults. Functional food brings an opportunity to improve nutritional value of commonly eaten products, e.g., pastry products. New trends in the food industry tend to produce low-calorie products by replacing sugar or fat with additives having pro-health benefits. The aim of this study was to determine the effect of replacing sucrose with steviol glycosides (natural non-caloric sweetener) on the quality properties of bakery products. The analysis of muffin's texture, color, cooking yield, browning index, and sensory analysis were performed. The study showed that a 25% addition of steviol sweetener (as a sucrose replacement) was the most appropriate modification of the basic formula. The resulting muffins gained sensory attractiveness and health-promoting qualities. Moreover, the study showed that a reduction of sucrose in excess of 50% had a negative impact on the quality of muffins and their sensory profiles.

Keywords: steviol glycosides, functional food, muffins, texture profile analysis, color

Introduction

As more consumers take interest in the nutritional benefits of food components, they become more aware and pay more attention to food products. Therefore, functional food has become an important branch of the food industry (1,2). This type of food is rich in valuable nutrients and can also be fortified with vitamins, unsaturated fats, polyphenols, or fiber (3).

Today, a major problem is rising global obesity, which is strongly connected with the overconsumption of sugar and fat (4). In particular, children and young people eat too much when it comes to sweetened products. Childhood overweight is a strong predictor of adult obesity (5). To tackle this problem, the food industry started to develop low-sugar and low-fat products with a quality that was comparable to that of traditional products (6). Common sweet snacks are bakery products, such as biscuits, muffins, or buns. In particular, muffins are widely popular because of their soft texture and great taste. Muffin batter is an emulsion created by a complex egg–sucrose–water–fat mixture subjected to a phase of continuous aeration. Bubbles create a desirable porous structure and high volume. Nevertheless, muffins are high in sugar and fat (7).

To limit the amount of added sugar and decrease the energy value of pastry products, one possible solution is to replace sugar with highly intensive sweeteners. However, sugar plays a significant role in

batter formulation. It influences the texture, color, moisture, flavor, and taste of pastry products. For this reason, maintaining an appropriate sensory and bulk quality of a product with either decreased sugar content or its full replacement is challenging (8,9).

Steviol glycosides, derived from *Stevia rebaudiana* (Bert.) Bertoni, are an example of a natural sweetener; they are approximately 300 times sweeter than sucrose (10,11). Steviol glycosides are said to be a non-caloric sweetener because of the way they metabolize (12). Steviol glycosides exhibit broad health-promoting, antioxidative, and antimicrobial properties (13,14). However, the most important property of steviol glycosides is normalizing glucose levels in blood and stimulating insulin secretion, which makes the use of steviol sweeteners, particularly for people with diabetes (15). The technological properties of steviol glycosides include high molecular stability in a wide range of temperatures and pH values, good solubility in water, high melting point, and non-fermentation properties. The most common and important steviol glycosides are stevioside (responsible for the bitter aftertaste) and rebaudioside A (the sweetest one) (16). There are different ways of incorporating steviol glycosides into foods, e.g., as a highly purified rebaudioside A powder or as a steviol glycoside mixture, as liquid extracts, or as tablets. It should be noted that the usage of steviol glycosides is limited in the European Union by Commission Regulation No 1131/2011 (17), which lays out the ADI (4 mg/kg bodyweight/day) and the maximum levels for different

products. For fine bakery wares, the maximum level is 330 mg/L or mg/kg.

Texture is one of the most important quality attributes. It refers to the sensory and functional properties of food (18). When used as a sucrose replacement, steviol glycosides may replace the sweet taste; however, they would not compensate for the missing bulk when sugar is decreased because of its higher weight and volume. As a result, a complete replacement of sucrose is not feasible without decreasing values of quality and texture parameters (9). Another important quality parameter is color, which influences consumer choice during shopping. Reducing the amount of sucrose in bakery products may contribute to poor color formation and increase lightness (19).

The aim of this study was to evaluate the feasibility of replacing sugar with steviol glycosides in the production of muffins. The effect of partial and total replacement on the most important quality properties was examined in order to develop the most suitable level of sucrose reduction in muffin production without having a negative influence on product quality.

Materials and Methods

Raw materials Ingredients used in dough preparation were commercial wheat flour (10.97% protein, 0.51% ash, and 28.6% gluten with a 14.04% moisture content) (Polskie Młyny, Inc., Warsaw, Poland), natural sweetener powder based on steviol glycosides for replacing sugar (label data: 95% steviol glycosides and 5% water) (NOW Foods Better Stevia™, Bloomingdale, IL, USA), refined sugar (Diamant, Gostyń, Poland), baking powder (Bakalland S. A., Warsaw, Poland), eggs, natural yogurt (Bakoma Sp. z o.o., Warsaw, Poland), rapeseed oil (ZT “Kruszwica” SA, Kruszwica, Poland), and salt (Cenos Sp. z o.o., Września, Poland).

Analysis of wheat flour composition As the first step of batter preparation, the wheat flour composition was examined. A sample of wheat flour was spread on a Petri dish and measured with near-infrared spectroscopy (NIRFlex N-500; Büchi Labortechnik, Flawil, Switzerland).

Batter preparation and muffin baking Muffins were made in 5 different formulations: the control sample (sweetened only with sugar (s0) and 4 samples with increasing levels of sucrose replacement 25% (s25), 50% (s50), 75% (s75), and 100% (s100); (Table 1). The basic formulation (ingredients calculated on 1 kg of flour) comprised wheat flour (1,000 g), sugar (400 g), eggs (7 pcs.), rapeseed oil (333 ml), natural yogurt (667 mL), baking powder (33 g), and salt (5 g). Sugar was replaced in by the steviol glycosides sweetener according to the conversion based on the instructions from the manufacturer NOW Foods Better Stevia™: 45 mg steviol powder is equivalent to 6 g of sugar. The degrees of sugar replacement by steviol glycosides

Table 1. The content of sweetening agents in different muffin formulas

Sample ¹⁾	Sugar	Natural sweetener based on steviol glycosides
	(g/kg wheat flour)	(mg/kg wheat flour)
s0	400	0
s25	300	750
s50	200	1,500
s75	100	2,250
s100	0	3,000

¹⁾s0, control sample (only sweetened with sugar); s25, sample with 25% of steviol sweetener; s50, sample with 50% of steviol sweetener; s75, sample with 75% of steviol sweetener; s100, sample with 100% of steviol sweetener.

were set only for scientific research. First, sugar and eggs were mixed for 180 s in a mixer at the highest speed (model MUM4675EU/04; Bosch, Gerlingen, Germany). Then, oil was gradually added and mixed for 120 s. Next, yogurt was gradually poured in and mixing was continued for another 60 s. Flour sifted with baking powder and salt (and optionally with stevia sweetener) was sprinkled onto wet ingredients and mixed for 120 s. Muffins were baked for 20 min at a temperature of 180°C in convection oven (model CPE 110; Küppersbuch, Gelsenkirchen, Germany) and cooled at ambient temperature. Baking temperature was determined through the following experiment.

The highest baking temperature to maintain the highest intensity of sweet taste was determined. Changes in the sweetness of the product could occur due to the decomposition of steviol glycosides at very high temperatures (20). Samples of 50% steviol sweetener were used to test the intensity of sweet taste. Muffins were baked for 20 min at 170, 180, 190, and 200°C. Then, the temperature in the geometric center of the product was measured using food thermocouple Testo 925 (Testo, Lenzkirch, Germany).

Cooking yield and browning index Muffin batter as well as the baked and cooled muffins were weighed and the cooking yield (CY) was calculated (1):

$$CY = \frac{w_a}{w_b} * 100\% \quad (1)$$

where

CY: cooking yield (%)

w_b: weight of sample before baking (g)

w_a: weight of sample after baking and cooling (g)

Browning index (BI) for crust and crumb of muffins was determined based on $L^*a^*b^*$ measurements. Calculations were made according to formula (2) written below (21):

$$BI = \frac{(100(x-0.31))}{0.17}, \text{ where} \quad (2)$$

$$x = \frac{(a^* + 1.75L^*)}{(5.645L^* + a^* - 3.012b^*)} \quad (3)$$

Instrumental color measurement The instrumental measurement of color components was determined using Minolta CR-400 colorimeter (Konica Minolta Inc., Osaka, Japan) with the CIE $L^*a^*b^*$ measuring system (aperture=8 mm, standard observer 2°, and illuminant D65). Before the analysis started, calibration had been done using white reference standard ($L^*=98.45$, $a^*=0.10$, and $b^*=0.13$). Values of L^* ($L=0$ black; $L=100$ white), a^* (a =greenness; $+a$ =redness), and b^* (b =blueness; $+b$ = yellowness) were measured 24 h after baking. Crumb and crust color analysis were performed 10 times at several points for each sample (muffins were cut horizontally).

Texture profile analysis Instrumental measurement of texture components was determined using a universal testing machine (Instron 5965; Instron, Canton, MA, USA) installed with the Bluehill 2 software. Results were obtained via texture profile analysis (TPA) wherein the sample was subjected to a double compression test between the compression probe (diameter= 57 mm) and the parallel base. A compression of 50% was used at head speed of 120 mm/min, with a cell capacity of 500 N. Muffins were cut into cubes of 20 mm×20 mm×20 mm. Experiment was performed 24 h after baking in 6 repetitions. The analyzed parameters were hardness (the highest force needed to compress the sample during first cycle, i.e., N), cohesiveness (the ratio of the surface area under the first and second compression graphs; –), and springiness (the ratio of the height reached after the first compression to the basic sample height; –) (18).

Sensory evaluation A well-trained sensory panel in a group of 20 people from the Department of Technique and Food Development (University of Life Sciences, Warsaw, Poland) evaluated the samples of muffins in a standardized tasting room equipped with individual boxes 24 h after baking. Samples were coded and randomly distributed on plastic plates. A cup of unsweetened tea was provided for rinsing the mouth after each evaluated sample (22). A hedonic 10-cm unstructured scale was used according to Polish Norm PN-ISO 4121:1998 (23) and PN-ISO 6658:1998 (24). The following attributes were rated: softness, moisture, porosity, sweet taste, color, and overall quality. Sensory evaluation was based on the methods used by Póltorak *et al.* (25) and Martínez-Cervera *et al.* (7) with several modifications. Moreover, the evaluation of the intensity of sweetness was done in order to determine the highest possible temperature of baking that would not cause a loss of sweet taste. The task was to rank the samples and indicate the degree of sweetness on an unstructured 10-cm scale. This assessment was performed using the same conditions as described above.

Statistical analysis of the results The results were analyzed statistically by a one-way analysis of variance, followed by Fisher's test using Statistica 12.0 (StatSoft Inc., Tulsa, OK, USA). The significance of differences was tested at $p \leq 0.05$.

Table 2. Evaluation of the highest temperature of baking that maintained the highest intensity of sweet taste

Baking temperature	Time	Temperature in geometric center of the sample	Sweetness intensity (a.u)
170°C	20 min	92°C	4.4
180°C	20 min	98°C	5.3
190°C	20 min	105°C	4.3
200°C	20 min	122°C	3.8

Results and Discussion

Evaluating baking temperature The optimal temperature was determined to evaluate the highest possible temperature of baking that would not cause a loss of sweet taste. A sample containing a 50% reduction in sucrose was baked at different mean temperatures. The results are summarized in Table 2. During baking, it was simultaneously determined that the higher the temperature was set in the oven, the higher the temperature was inside the product. During sensory evaluation, the highest score for sweetness intensity was obtained by a sample baked at 180°C, whereas the lowest score was obtained for a sample baked at 200°C. Based on this experiment, a baking temperature near 180°C was chosen for the remaining stages of the experiment.

CY Changes in the values of CY parameter are summarized in Table 3. It was observed that the higher was the degree of substitution of sucrose with steviol glycosides, the lower was the value of CY. The highest mean of this parameter characterized the control sample, while the lowest mean characterized the sample without sucrose (s100), which was statistically significant. According to Raoult's law of thermodynamics, a higher concentration of a substance in a water mixture is responsible for higher evaporation temperature (26). Due to the replacement of sucrose in the batter with the steviol glycosides, the concentration of saccharides is lower. The CY parameter is dependent on the mass difference before and after baking. The main factor influencing this parameter is the water content, which evaporates during the heating of the batter, leading water to form the final product. When the sucrose is less concentrated in product, the water evaporation temperature is lower. This means that more water is susceptible to evaporate, and therefore, it results in lower final product mass, which consequently results in decreasing yield value.

Muffin color and BI Changes measured in the color of the crumb and crust are summarized in Table 4. A gradual replacement of sucrose with natural sweetener resulted in a slight increase in the lightness of the crumb and a significant increase of BI parameter in the muffin crust. The highest lightness for crumb and crust was observed in the samples s75 and s100. In addition, an increase in

Table 3. Mean and standard deviation of cooking yield (%) and selected texture parameters for muffins with different degrees of sucrose replacement

	Cooking yield (%)	Crumb texture		
		Hardness (N)	Springiness (—)	Cohesiveness (—)
s0 ¹⁾	87.51±2.21 ^{c2)}	4.99±1.09 ^a	0.70±0.02 ^a	0.40±0.03 ^a
s25	86.29±2.45 ^{b,c}	6.30±0.80 ^{ab}	0.71±0.06 ^a	0.40±0.02 ^a
s50	84.11±1.05 ^{ab}	6.30±1.19 ^{ab}	0.74±0.04 ^b	0.44±0.02 ^b
s75	84.99±2.25 ^b	6.76±0.73 ^{ab}	0.78±0.02 ^b	0.43±0.03 ^b
s100	82.15±2.05 ^a	7.78±1.51 ^b	0.78±0.03 ^b	0.42±0.03 ^{ab}

¹⁾s0, control sample (only sweetened with sugar); s25, sample with 25% of steviol sweetener; s50, sample with 50% of steviol sweetener;

s75, sample with 75% of steviol sweetener; s100, sample with 100% of steviol sweetener.

²⁾Means with different letters within the same column are significantly different ($p \leq 0.05$).

Table 4. Mean and standard deviation of color values ($n=10$) and browning index for muffin's crust and crumb within samples with different degrees of sucrose replacement

	Color						Browning index	
	Crust			Crumb			Crust	Crumb
	L^*	a^*	b^*	L^*	a^*	b^*		
s0 ¹⁾	64.22±1.24 ^{a2)}	9.50±0.71 ^d	31.90±1.76 ^{cd}	73.34±2.86 ^a	2.13±0.35 ^a	20.06±1.41 ^a	45.62±3.97 ^a	28.82±2.07 ^a
s25	69.49±1.99 ^b	8.85±1.31 ^d	32.84±0.90 ^d	75.30±2.48 ^{ab}	2.23±0.33 ^{ab}	21.02±0.52 ^b	52.99±3.46 ^b	29.70±1.73 ^a
s50	73.57±1.01 ^c	6.56±0.67 ^c	31.31±1.19 ^c	74.58±1.81 ^{ab}	2.29±0.23 ^{ab}	21.56±0.82 ^{b,c}	60.69±3.81 ^c	30.91±1.03 ^{ab}
s75	75.13±1.9 ^d	5.53±0.70 ^b	28.91±1.18 ^b	75.77±1.67 ^b	2.11±0.17 ^b	22.52±0.95 ^c	71.79±6.19 ^d	32.19±1.88 ^b
s100	76.48±1.39 ^d	3.65±0.63 ^a	26.72±1.55 ^a	75.82±1.88 ^b	1.98±0.36 ^b	22.39±1.13 ^c	77.65±6.51 ^e	32.70±2.14 ^b

¹⁾s0, control sample (only sweetened with sugar); s25, sample with 25% of steviol sweetener; s50, sample with 50% of steviol sweetener, s75, sample with 75% of steviol sweetener; s100, sample with 100% of steviol sweetener.

²⁾Means with different letters within the same column are significantly different ($p \leq 0.05$).

greenness (a^*) and increase in yellowness (b^*) was observed in the muffin crumb. Similar results were obtained by Martínez-Cervera *et al.* (7), who examined muffins with reduced sucrose content after having it replaced with a mixture of sucralose and polydextrose. As the amount of non-sucrose sweeteners in the experimental formulation was increased, the lightness of the muffin crust increased, along with the saturation of yellowness (b^*) and redness (a^*). Thus, where the BI parameter was concerned, an increasing degree of substitution of sucrose corresponded to a significant increase in lightness for muffin crust and a slight increase for muffin crumb. The abovementioned changes in lightness and BI are associated with caramelization and the Maillard reaction (non-enzymatic browning) between reducing sugars and amino acids. Sucrose (non-reducing sugar) decomposes into glucose and fructose (reducing sugars) at higher temperatures. Therefore, if the amount of sucrose is decreased, the development of color is worse because less Maillard reaction products (MRPs) are formed. MRPs are responsible for the flavor, taste, and color of the baked products (27).

Muffin texture Muffin texture profile was analyzed via the TPA test (Table 3). Three parameters were measured: hardness, springiness, and cohesiveness. Results showed that hardness and springiness increased as more sucrose was replaced with steviol glycosides. On the other hand, cohesiveness did not significantly change. Similar results were observed in a study by Kulthe *et al.* (28), where

hardness, thickness, and diameter of the cookies were decreased when 15-20% of sucrose was replaced with the stevia powder. In contrast, opposite results were achieved by Ronda *et al.* (29) (with polydextrose as a replacement for sucrose) and Martínez-Cervera *et al.* (7) (with a mixture of sucralose and polydextrose as a replacement for sucrose) because muffins with a reduced amount of sucrose were characterized by a softer texture due to a decrease in the hardness values. Replacing 25% of the sucrose with sucralose and polydextrose had no influence on the overall quality of muffins the way it was demonstrated in this study. However, Martínez-Cervera *et al.* (30) compared polyol sweeteners like maltitol, erythritol, or sorbitol, which have different influences on muffin texture. This suggests that the changes in texture parameters depend not only on reducing the amount of sucrose in the batter formula but also on the sucrose replacement material. Furthermore, increasing hardness values were inversely correlated with the CY parameter. This may suggest that the more the water evaporates from the cake during baking, the more compact is the crumb structure. This effect could also be connected with the sucrose property of delaying protein denaturation and starch gelatinization (as it raises the temperatures of these processes). Because of the hygroscopicity of sucrose, starch, gluten, and sucrose compete for water (31). A lower concentration of sucrose or its complete absence changed the temperatures of gelatinization and gluten hydration and consequently influenced water migration. This may be the reason for the higher value of muffin's hardness. The lack

Fig. 1. Scores for sensory evaluation of muffins sweetened with steviol glycosides. s0, control sample (only sweetened with sugar); s25, sample with 25% of steviol sweetener; s50, sample with 50% of steviol sweetener; s75, sample with 75% of steviol sweetener; s100, sample with 100% of steviol sweetener.

of delay in protein denaturation and starch gelatinization may have resulted in inappropriate formation of air bubbles in the batter due to water evaporation and carbon dioxide migration during baking: this happened before the cake structure hardened. Furthermore, sucrose participates in the incorporation of air bubbles into the batter/dough during mixing, which then spread during baking (9). Thus, the decreased amount or complete replacement of sucrose results in weak cell development. It may also cause firm, low-raised, and undesirable cake structures.

Sensory evaluation The trained sensory panel rated the following muffin attributes: crumb color, crumb softness, moisture, porosity, sweet taste, and overall quality. Results are shown in Fig. 1. A sample with 25% of sucrose replaced with steviol glycosides was the most desirable sample. It obtained the highest scores for the factors such as color, porosity, and overall quality. The sample sweetened only with steviol sweetener (s100) was characterized by the deterioration of taste, moisture, color, and overall quality of muffins. Generally, sensory attributes were assessed to be less desirable with the increase in sucrose replacement. Furthermore, the control sample was noted as the most acceptable sample in terms of sweetness. This result indicates that consumers still prefer the traditional taste of sucrose.

Replacing sugar with steviol glycosides is possible but only as a partial contribution to the total amount of sweetener. Replacing more than 50% of sucrose resulted in difficulties with maintaining the quality and sensory parameters. This was mainly because of the increased hardness, decreased springiness and cohesiveness, and a less acceptable taste. This confirms the fact that sucrose is a very important compound in the development of batter cakes. The best performing formula was a 25% replacement of sucrose with steviol sweetener. This sample was characterized by the best overall quality

in sensory evaluation as well as comparable texture and color parameters to the control sample. Using natural steviol sweetener in pastry products as a replacement for sucrose is an innovative and pro-healthy alternative for synthetic sweeteners and provides the opportunity for reducing energy intake. Further research should be conducted in terms of optimizing formulas for different food products.

Disclosure The authors declare no conflict of interest.

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