

Katarzyna Król, Alicja Ponder, Magdalena Gantner

Faculty of Human Nutrition and Consumer Sciences, Department of Functional Food, Ecological Food and Commodities, Warsaw University Life of Sciences

ul. Nowoursynowska 159c, 02-776 Warsaw, Poland, katarzyna_krol@sggw.pl

THE EFFECT OF SUGAR SUBSTITUTES ON SELECTED CHARACTERISTICS OF SHORTCRUST PASTRY

Abstract

The aim of this study was to evaluate the possibility of substituting sugar in crust pastry with natural substitutes, such as stevia, xylitol, coconut sugar as well as dried banana. Furthermore, a comparison of physicochemical properties was carried out. The crust pastry obtained was analyzed in terms of color by CIEL*a*b*, textures, water activity, bake loss, semi-consumer assessments and the nutritional value was calculated. There was a clear impact caused by the sugar substitute on the physicochemical properties and their sensory assessment. The cakes with xylitol had the closest color, smell and taste to the control sample (with sucrose). The cakes with dried banana had a significantly reduced hardness compared to the control sample. The lowest bake loss was observed in the case of pastry with dried banana, while the highest was in the case of xylitol. In sensory analysis, the “Just-about-right” method was used, and pastries with a sweeter taste were more desirable (xylitol) and pastry with the stevia substitute showed the lowest desirability. The lowest energy value per 100 g was obtained for stevia (392 kcal/ 100g), while for xylitol energy, the value was reduced by 6%.

Key words

Xylitol, stevia, dried banana, coconut sugar, crust pastry

Introduction

Sugar, which is currently consumed by society in increasing quantities, is a substance that causes many diseases, known as civilization diseases, such as obesity, diabetes, hypertension and coronary heart disease [1]. However, Sucrose in bakery products makes a major contribution to providing sweetness, controlling moisture retention, influencing air incorporation, stabilizing air bubbles, and limiting the swelling of starch during baking, all of which help to create a finer texture [2].

The baking industry is currently witnessing a situation in which the labeling claims of products, like sugar free, reduced calorie, gluten-free and fibre rich, are attracting health-conscious consumers. Consumers are becoming more and more aware of this, and out of concern for their own health, often choose healthier products. Due to this, the food industry, over the last several years, has been investigating ways to reduce the levels of free sugars within their products to comply with guidelines and regulations, such as those of the World Health Organization, which has made a strong recommendation to reduce the level of sugar in the diet to less than 10%, and preferably as low as 5% [3, 4]. It is important to find alternative sugar replacers for traditional sugars in order to improve the quality of low-sugar pastry products. The energy content of sweet bakery products may be appropriately reduced by substituting sucrose with non-nutritive, naturally occurring (further denoted as natural) or artificial high-intensity sweeteners. Sweeteners can be classified according to the following criteria:

- Origin (natural or artificial),
- Consistency (powders/syrups),
- Energy value (nutritive or non-nutritive),
- Technological function (bulking agent or sweeteners).

Stevia is a glycoside isolated from the plant *Stevia Rebaudiana Bertoni* [5]. Stevioside can be isolated from dried leaves and is approximately 300-400 times sweeter than sucrose, however the bitterness that presents as an aftertaste affects the sensory quality of the final product [6]. Some studies have suggested that stevia increases insulin sensitivity and glucose tolerance in human cells and safety issues concerning stevia showed no negative side effects. Furthermore, stevia glycosides were recently approved for use as a sweetener by the

Joint Food and Agriculture Organization/World Organization Expert Committee on Food Additives and ADI is 4 mg/kg day [7].

Xylitol is a sugar alcohol obtained by replacing an aldehyde group with a hydroxyl group. Xylitol is the sweetest of the polyols, being equivalent to sucrose in sweetness, but with fewer calories, and lower glycemic index [8, 9]. The most common application of xylitol is in chewing gum, because it is very convenient due to its sensory properties. It is also used in candies, gelatins, chocolate, yogurt, and a wide range of confectionery products. Furthermore, xylitol dissolves in the mouth to give a pleasant sensation of cooling and freshness after consumption [10].

Coconut sugar has been used as a traditional sweetener in Asia and is now gaining popularity because of its natural and minimal processes. A recent work has stated that the GI of coconut sap sugar was reported to be in the low category (35-45) [11]. The main component of coconut sugar is sucrose (about 70-80%) combined with glucose (3-9%) and fructose (3-9%). Palm sugar is produced from filtered juice, which is heated for several hours at a temperature of about 100°C until concentration and a typical aroma is obtained. The Maillard reaction and caramelization occur during the processing of palm sugar [12].

Dried bananas can be used as substitute for sugar, because of its sweet taste. Mostly, dried banana consists of simple sugars as well as dietary fibre (starch) (6.4g / 100g). Dried bananas contain about 4 times more potassium, calcium, phosphorus and magnesium and other minerals than the fresh ones. Their energy value is 97kcal / 100g [13].

However, the decrease in the sucrose content is accompanied by significant changes in texture, volume, colour, taste, hardness, surface finish and shelf life of the product. These changes may negatively influence product acceptability and also affect processing properties of doughs or batters. Furthermore, sugar substitutes have high sweetness intensity but it does not support texture characteristics [14]. Non-caloric sweeteners does not participate in Maillard reaction or caramelization resulting in lighter color after baking. Furthermore, sugar alcohol have lower humectancy and do not retain a moistness compared to sugar [15]. There are many published studies that show reduced sucrose products to be less acceptable than their full-sucrose counterparts [15, 16, 17, 18].

The objective aim of this study was to investigate the possibility of replacing sugar with different natural sweeteners in making short crust pastry. For this purpose, four different substitutes were used (stevia, xylitol, coconut sugar, dried bananas). Then, the physical and sensory properties of cakes were evaluated.

Materials and methods

The material was short crust pastry. As the basic ingredients 200 g flour (type 450), 30 g egg yolk, 120 g butter (83% of fat) and 2 g salt were used for every type of cake. In the cake with xylitol and coconut sugar formulation, 60 g was used, with stevia 0,2 g, with dried banana 70 g. The control sample was made using saccharose (60g) as a sweetener. Then, all ingredients were mixed in mixer (Kenwood Major Classic) for a 5 min and then covered in plastic wrap and refrigerate the dough for 30 min. After that was baked in a convection oven (Kuppersbusch 10xGN1/1/) 180°C for 30 min. Each of the prepared samples weighed 170 g and were baked in silicone mold with 20 cm diameter and were prepared in 8 replications. The samples were cooled at room temperature for 10 minutes, covered by cellophane and finally kept at an ambient temperature, in a dry and dark place, until they were analyzed. For sensory evaluation the samples were prepared one day before of each trial.

Water activity (a_w) was measured at $20 \pm 2^\circ\text{C}$ on 2 replicates for each sample with a dew point hygrometer Aqualab® series 3 TEV (Decagon Devices Inc., Pullman, WA., U.S.A. The bake loss of pastry was calculated by weighing one piece before and after baking. The difference in weight was averaged and reported as a percentage bake loss.

The instrumental measurement of the colour of the pastry was performed in the $L^*a^*b^*$ color system, where L^* – lightness, a^* – the colour axis ranging from greenness ($-a^*$) to redness ($+a^*$), b^* – colour axis ranging from blueness ($-b^*$) to yellowness ($+b^*$). The colour was measured by a Minolta chromameter (CR-400, Konica Minolta Inc., Tokyo, Japan). The chromameter was calibrated using a white standard plate

($L^* = 98.45$, $a^* = -0.10$, $b^* = -0.13$). A measuring head with a diameter of 8mm and a D65 illuminant was used. The determination of colour parameters was performed by randomly measuring 10 different places on each surface. The total colour change (ΔE) is a measure of the difference between the control sample and a tested sample and was calculated using the following equation: $(\Delta E^* = [(L_1^* - L_2^*)^2 + (a_1^* - a_2^*)^2 + (b_1^* - b_2^*)^2]^{1/2})$.

For measuring the textural properties of cakes, an Instron universal testing machine (Model 5965, Instron, Canton, MA, USA) with Bluehill®2 software was used, which included a compression test. The compression test was carried out using a flat probe. A sample deformation was limited to 50% for all the determined parameters. This deformation percentage was found to be sufficient to break a crusty pastry. The test was conducted 6 times, where one speed test (10 mm/min) was applied. The force curve (N) versus distance (mm) allows the hardness to be calculated. The hardness of the short crust pastry was designated as the maximum compression force (N). Ten replicates of each formulation were conducted.

In the sensory evaluation of the pastry, the “Just About Right” (JAR) method was used and 39 (28 female, 11 male) participants were invited to semi-consumer analysis. For each sample, participants were asked to rate their overall liking and attribute intensity. The attributes assessed included: hardness, colour, odour, crispness, sweet flavour and metallic aftertaste. “Just-about-right” (JAR) scales were designed as continuous line scales (-4 to 4) with three descriptive anchors, low intensity (“Much Too Weak”) on the left end, (“Just About Right”) at the centre, and high intensity (“Much Too Strong”) on the right end. Samples were served in a sequential order, with a minimum two-minute mandatory break between each sample. Participants rinsed with filtered water between samples to reduce potential carry-over effects.

The caloric value of pastry was calculated on the basis of the information on the packaging (fat 9 kcal/1 g, protein, carbohydrate, saccharose, dried banana, coconut sugar 4 kcal/1g, stevia 0,2 kcal/1 g). At the beginning, the energy value of the whole product was obtained, and then it was converted into 100g of product and per portion of product, which was taken as 30g.

Statistical analysis: all experiments were carried out in triplicate and average values with standard deviation were calculated. The statistical differences were checked using the one-way ANOVA method and Tukey’s post-hoc test (at a significance level $\alpha=0.05$). P-values lower than 0.05 were considered statistically significant and homogenous groups were noted with the same letters in tables. Analyses were conducted using Statistica Software version 12.0 (StatSoft, Tulsa, USA).

Results and discussion

The physical properties (water activity, bake loss, colour parameters and hardness) of four types of pastry are shown in Table 1. Results showed that there was significant difference ($p < 0.05$) between each sample in terms of a_w , bake loss, L^* , a^* , b^* , ΔE^* and hardness.

Water activity is an important indicator for product design, shelf-life and food safety. If a product is kept below a certain water activity, then it is possible to inhibit the growth of fungi/bacteria/mold, thus the shelf-life is longer. In the case of the a_w sample with xylitol (0.67), it was characterized by a lower level and other samples were in a homogeneous group and varied from 0.70 to 0.76. Water activity in the range 0.55-0.9 is considered as medium water activity, and bacteria usually require at least 0.91 and fungi at least 0.71. All of our samples are in this group and the growth of bacteria is inhibited. Furthermore, xylitol is more hygroscopic than sucrose, therefore, it seems reasonable that partial or complete elimination of sucrose led to a reduction in the water activity of dietetic pastry [14]. However in our study polyols showed a lower water activity than sample with saccharose, what is not in consistent with studied conducted by Majeed et al. (2018) [22], but is in close agreement with study conducted by Nourmohammadi and Peighambardoust (2016) [15]. Investigated by Winkelhausen et al. (2007) [19], xylitol improved microbial stability and shelf-life of cakes as it provided lower water activity at the same concentration with sucrose, which was confirmed with obtained results In our study.

Table 1. Physical properties of short crust pastry obtained from different sweeteners (coconut sugar, dried banana, xylitol, stevia and saccharose).

	Coconut sugar	Dried banana	Xylitol	Stevia	Control sample
a_w	0.73	0.70	0.67	0.71	0.76
Bake loss (%)	17.01 ± 0.34^b	16.21 ± 0.21^b	20.21 ± 0.11^c	20.23 ± 0.20^c	14.21 ± 0.12^a
L^*	42.43 ± 0.20^a	46.23 ± 0.04^a	68.24 ± 0.14^{bc}	70.54 ± 0.11^c	63.03 ± 0.26^b
a^*	12.5 ± 0.12^c	8.62 ± 0.12^b	10.22 ± 0.16^c	4.92 ± 0.03^a	11.04 ± 0.03^c
b^*	25.70 ± 0.08^a	35.82 ± 0.22^b	37.26 ± 0.03^b	34.80 ± 0.07^b	35.54 ± 0.24^b
ΔE^*	20.72 ± 1.21^b	3.54 ± 0.18^a	3.32 ± 0.19^a	3.01 ± 0.03^a	-
Hardness (N)	15.02 ± 1.32^b	6.69 ± 0.95^a	25.04 ± 0.46^c	6.94 ± 0.54^a	13.52 ± 0.59^b

Values are expressed with the standard deviation. Lowercase letters in rows (a-c) show between which samples were statistical differences ($p < 0.05$).

Source: Author's

The bake loss of pastry was the smallest and similar for the control sample, coconut sugar and dried banana, while the highest was for xylitol and stevia. Dried banana have a higher water holding capacity compared to sweeteners, due to its higher protein content [13]. Proteins would increase water holding capacity, thus enhancing the swelling ability, an important function of protein in preparation of viscous foods such as soups, dough and baked products [24]. Similar results was obtained by Akesowan (2009) [25] bake loss was increased compared to control sample with saccharose.

The colour values measured by a colorimeter showed that L^* was the smallest for coconut sugar and the highest for stevia. The lightness (L^*) of short crust pastry displayed an increasing trend along with the increasing substitution level of sugar (stevia and xylitol). For a^* coordinate (redness) the highest was coconut and the control sample, the smallest for samples with sweeteners. For b^* coordinate (yellowness) only the sample with coconut sugar showed a lower value of b^* , other samples are in a homogeneous group. The darker colour of pastry from coconut sugar and dried banana is correlated with the initial darker colour of the product. Furthermore, some authors have suggested that the darker color of the pastry is related to higher protein as well as sugar content, and thus a more intense Maillard reaction (browning and caramelization of sugar is considered to produce brown pigments during baking) [13]. Furthermore, it is believed that sugar alcohols (xylitol) and stevia are not able to participate (thermal stability) in the Maillard reaction due to the lack of functional groups [14]. This is in keeping with the findings of Martínez-Cervera et al. (2011) [25], which showed the addition of erythritol in muffins appeared not to influence the crust color. Furthermore, Gao et al. (2017) [21] also reported increase of L^* value in muffins with stevia as a sweetener, what is in close agreement with obtained results.

The results of the hardness showed that pastry made with dried banana and stevia decreased significantly at the 55-56% level compared to the control sample and increase in the case of the sample made with coconut sugar and xylitol at 10%-84% level. According to Nourmohammadi and Peighambardoust [13] the investigated correlation between water activity and hardness (the higher the water activity, the higher the crumb firmness) was also obtained from this study. Other studies showed that replacing sugar with polyols may effect on decrease of hardness and firmness of cakes compare to control samples with saccharose [27].

Table 2. Evaluation of the nutritional composition of the short crust pastry obtained

	Coconut sugar	Dried banana	Xylitol	Stevia	Control sample
Energy (kcal)	448	450	427	392	452
Protein [g]	6.5	7.1	6.5	6.5	6.5
Carbohydrates [g]	50	52	49	36	51
Sugar [g]	13.5	0	0	0	15
Fat [g]	24	24	24	24	24
Fibre [g]	1.2	2.2	1.2	1.2	1.2

Source: Author's

The results of nutritional composition are shown in Table 2. The proximate values of sugar decreased with the increased level of sugar substitutes. The high energy values were the results of high fat content (24g/sample) which provide 9kcal/1 gram. The proximate values of energy and sugar were highest in the control sample, while the lowest was in the stevia sample, where the energy was reduced by 13% and carbohydrates by 30%.

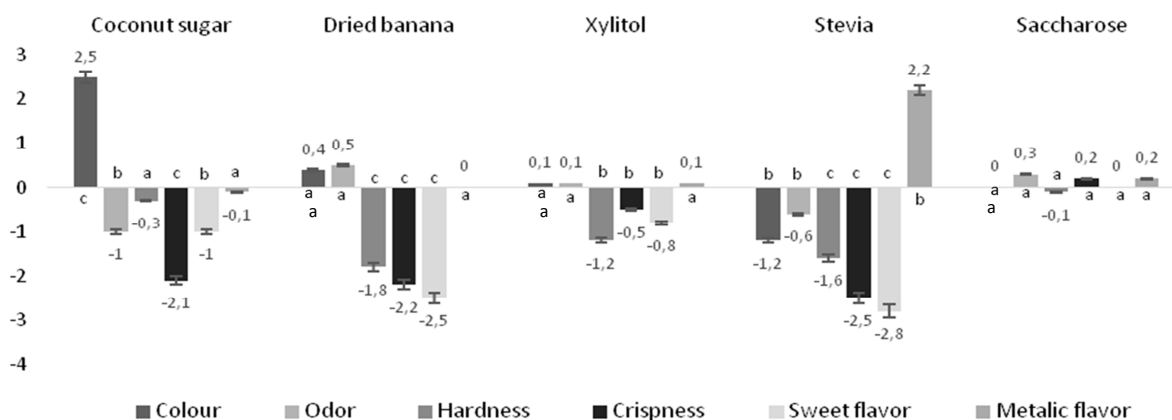


Fig. 1. The effect of the replacement of sugar with coconut sugar, dried banana, xylitol and stevia on the sensory characteristics of short crust pastry. Lowercase letters on figure (a-c) show between which samples were statistical differences ($p < 0.05$).

Source: Author's

In the sample with dried banana, an increase of protein and fibre content was observed in the range between 8.5% and 90%, respectively. The lower content of sugar in the sample with coconut sugar is the result of minimal processing and a higher content of dietary fibre, especially inulin. These could play an important role in lowering the GI values of palm sugars when compared to refined sugarcane which contains almost 100% of sucrose [9, 15].

The sensory scores of short crust pastry with sugar substitutes are presented in Figure 1. The JAR scale was selected as it is designed to find the optimum/most appropriate level of a specific attribute and is easy for panelists to understand. According to the presented results, there was a significant difference between all investigated samples ($p < 0.05$). The largest deviations from the control sample were recorded for the sample with stevia, where colour, odour, hardness, crispness sweet flavor were "too weak"/"much too weak", while a metallic aftertaste was determined as "too strong". According to the sensory evaluation, stevia as a substitution in cakes resulted in the occurrence of a little bitterness which is attributed to the inherent bitterness of steviol glycosides [28]. Mean JAR rating for the colour of samples with dried banana and xylitol was similar to the control sample, while for coconut sugar the colour was "too strong". The smallest deviations from the standard were recorded for the xylitol sample, which revealed that short crust pastry with xylitol reformulation was found to be most acceptable by the panelist. To the best of our knowledge, this is the first work presenting JAR sensory analysis of short crust pastry, however, other studies with sugar replacements showed that, in sensory evaluation, samples with xylitol were the best substitute for the sugar contained in cakes [17, 19] and results are in close agreement with results obtained by Winkelhausen et al. [19].

Summary and conclusions

Sweeteners cannot solely replace sugar and the food industry, however it is important to find alternative sugar replacers for traditional sugars in order to improve the quality of low-sugar cakes. To summarise, sweeteners influenced the physicochemical (a_w , colour, hardness and bake loss) properties of short crust pastry. The caloric content of pastry with coconut sugar, dried banana, xylitol, stevia and sucralose are 448, 450, 427, 392, 452 kcal/100g, respectively (estimated by the raw materials used for each cake). Sugar alcohol such as xylitol, among the four tested substances, was found to be the best substitute and in the sensory evaluation score was similar to sugar-containing short crust pastry and physical properties (a_w , color coordinates) were comparable to control sample. However, for wider acceptance of products with xylitol, consumers should be educated and learn more about the benefits of xylitol itself. However, further optimizing is required to obtain muffins with satisfactory textural properties and mouthfeel and an appealing appearance that would satisfy consumer preference.

References

- [1] D. Włodarek, E. Lange, L. Kozłowska, D. Głąbska, *Dietoterapia*. Wydawnictwo Lekarskie PZWL, Warszawa 2014, 188, 252-253, 257, 259, 274, 282.
- [2] Y.-H. Hui, W.-K. Nip, *Sweeteners*, In: W. Zhou, Y. H. Hui (Eds.), *Bakery Products: Science and Technology*, Wiley-Blackwell, Oxford, UK, 2006, pp. 137–160.
- [3] World Health Organization (WHO) *Guideline, Sugars Intake for Adults and Children*, WHO, Geneva, 2015.
- [4] D. Martyn, M. Darch, A. Roberts, H. Youl Lee, T. Tian, N. Kaburagi, P. Belmar, *Low-/No-Calorie Sweeteners: A Review of Global Intakes*. *Nutrients* 10 (2018) 357.
- [5] A. Sclafani, M. Bahrani, S. Zukerman, K. Achroff. *Stevia and saccharin preferences in rats and mice*. *Chem Senses* 35 (2010) 433-443.
- [6] US Food & Drugs Administration, *Code of federal regulations title 21. Chapter I, Subchapter B*, Washington, DC, 2012.
- [7] S.D. Anton, C.K. Martin, H. Han, S. Coulon, W.T. Cefalu, P. Geiselman. *Effects of stevia, aspartame, and sucrose on food intake, satiety, and postprandial glucose and insulin levels*. *Appetite* 55 (2010) 37-43.
- [8] T. Varzakas, A. Labropoulos, S. Anestis (Eds.), *Sweeteners: Nutritional Aspects, Applications, and Production Technology*, CRC Press, Boca Raton, 2012.
- [9] R. Pulicharla, L. Lonappan, S.K. Brar, M. Verma, *Production of renewable C5 platform chemicals and potential application*, in: S.K. Brar S.J. Sarma, K. Pakshirajan (Eds.), *Platform Chemical Biorefinery*, Elsevier, Amsterdam, 2017, pp. 201-216.
- [10] Y. Arcano, O. Garcia, D. Mandelli, W. Carvalho, L. Pontes, *Xylitol: A review on the progress and challenges of its production by chemical route*, *Catalysis Today* 8 (2018) DOI: 10.1016/j.cattod.2018.07.060.
- [11] T.P. Trinidad, A.C. Mallillin, R.S. Sagum, R.R. Encabo, *Glycemic index of commonly consumed carbohydrate foods in the Philippines*, *Journal of Functional Foods* 2 (2010) 271-274.
- [12] K. Srikaeo, R. Thongta, *Effects of sugarcane, palm sugar, coconut sugar and sorbitol on starch digestibility and physicochemical properties of wheat-based foods*, *International Food Research Journal* 22 (2015) 923-929.
- [13] P.P. Subedi, K.B. Walsh, *Assessments of sugar and starch in intact banana and mango fruit by SWNIR spectroscopy*, *Postharvest Biology and Technology* 62 (2011) 238-245.
- [14] A.M. Abdel-Salam, A.S. Ammar, W.K. Galal, *Evaluation and properties of formulated low calories functional yoghurt cake*, *Journal of Food, Agriculture & Environment* 2 (2009) 218–221.
- [15] E. Nourmohammadi, S. Peighambardoust, *New Concept in Reduced-Calorie Sponge Cake Production by Xylitol and Oligofructose*, *Journal of Food Quality* 39 (2016) 6.
- [16] L. Laguna, P. Varela, A. Salvador, T. Sanz, S.M. Fiszman, *Balancing texture and other sensory features in reduced fat short-dough biscuits*, *Journal of Texture Studies* 43 (2011) 235–245.
- [17] A., Chauhan, D.C. Saxena, S. Singh, *Physical, textural, and sensory characteristics of wheat and amaranth flour blend cookies*, *Food Science & Technology* 2 (2016) 1125773.
- [18] P.K. Vayalil. *Date fruits (Phoenix dactylifera Linn): An emerging medicinal food*, *Critical Reviews in Food Science and Nutrition* 52 (2010) 249-271.

- [19] E. Winkelhausen, R. Jovanovska-Malinovska, E. Velickova, S. Kuzmanova, Sensory and Microbiological quality of a baked product containing xylitol as an alternative sweetener, *International Journal of food properties* 10 (2010) 639 – 649.
- [20] S. Struck, D. Jaros, C.S. Brennan, H. Rohm, Sugar replacement in sweetened bakery goods, *International Journal of Food Science and Technology* 49 (2014) 1963–1976.
- [21] J. Gao, M.A. Brennan, S.L. Mason, C.S. Brennan, Effects of Sugar Substitution with “Stevianna” on the Sensory Characteristics of Muffins, *Journal of Food Quality* 2 (2017) 1-11.
- [22] M. Majeed, M. Mohmod, M.U. Khan. M. Fazel. M. Shariati, I. Pigorev, Effect of sorbitol on dough rheology and quality of sugar replaced cookies, *Potravinarstvo Slovak Journal of Food Sciences* 1 (2018) 50-56.
- [23] S.M. Savita, K. Sheela, S. Sunanda, A. G. Shankar, P. Ramakrishna, Stevia rebaudiana—A Functional Component for Food Industry, *Journal of Human Ecology*, 4 (2004) 261-264.
- [24] A. Akesowan, Quality of Reduced-Fat Chiffon Cakes Prepared with Erythritol-Sucralose as Replacement for Sugar, *Pakistan Journal of Nutrition* 8 (2009) 1383-1386.
- [25] S. Martínez-Cervera, A. Salvador, B. Muguerza, L. Moulay, S. M. Fiszman, Cocoa fibre and its application as a fat replacer in chocolate muffins, *LWT—Food Science and Technology* 3 (2011) 729–736.
- [26] V. Psimouli, V. Oreopoulou, The effect of alternative sweeteners on batter rheology and cake properties. *J. Food Sci. Agric.* 92 (2012) 99–105.
- [27] M.C. Carakostas, L.L. Curry, A.C. Boileau, D.J. Brusick, Overview: the history, technical function and safety of rebaudioside A, a naturally occurring steviol glycoside, for use in food and beverages, *Food and Chemical Toxicology*, 7 (2008) S1–S10.
- [28] E. Gallagher, C. O’Brien, A. Scannell, E. Arendt, Evaluation of sugar replacers in short dough biscuit production. *Journal of food engineering* 56 (2003) 261-263.