

# Development and quality characteristics of sugar and fat free muffins utilising stevia and chia mucilage

G. Gökşen\* , Ç. Bakachan and H.I. Ekiz

Department of Food Engineering, Faculty of Engineering, Mersin University, Mersin, 33343, Turkey

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### ABSTRACT

Cake is a popular bakery product consumed by almost everyone due to its low economic cost and shelflife, however, it is recognised unhealthy because of high fat and sugar contents. The aim of this study was to evaluate physicochemical and sensory properties of muffins baked using 100% of sugar and fat replacement as stevia sweetener (rebaudioside A and erythritol) and chia seed mucilage, respectively. The combination of sweetener with chia gel (SCC) had the highest moisture content, while the replacement of fat in muffin (CC) revealed similarity to the control in lightness and redness values. There was also no significant difference in terms of firmness when only the sweetener was replaced (SC). While the control muffin obtained the highest overall acceptability score, the lowest score was observed in CC. Thus, muffins with reduced fat and sugar contents can benefit the consumer in terms of health, but further optimisation of formulations for both replacers is needed for better sensory acceptance.

### KEYWORDS

stevia, erythritol, chia gel, colour parameters, textural properties, sensory analysis

\* Corresponding author. Tel.: +90 3243610001; fax: +90 3243610032. E-mail: gulgok@mersin.edu.tr

## 1. INTRODUCTION

Eating habits of consumers have changed with their purchase behaviour, and nutritious, ready to eat, and easy-to-transport food products are sought after. Bakery products such as bagels, biscuits, cakes are favoured in this category all over the world (Zahn et al., 2010; Aranibar et al., 2019). Cakes are high-calorie bakery products that are popular due to their taste and texture (Gao et al., 2017). The consumption of high amounts of fats and sugars has been associated with serious health problems (Felisberto et al., 2015). As a result, food industry has focused on healthier products by producing low-calorie foods, but recurring problem is that these products have negative organoleptic qualities (Gao et al., 2017). Sugar not only provides the sweetness of the product, especially in foods, but is also an essential ingredient for the formation of its rheological and textural properties (Zahn et al., 2013). In addition, fat provides various advantages such as higher volume, softness, and pleasant mouthfeel in the final product, as it allows increased amount of air to be added during cake battering and prevents gas bubbles from coalescence (Rodríguez-García et al., 2014; Majzoobi et al., 2018). Different ingredients have been tried for substitution of sugar and fat in foods over the years (Martínez-Cervera et al., 2012; Struck et al., 2014).

The sweetener is generally a combination of rebaudioside-A and erythritol originally developed for a consumer market. Rebaudioside-A is extracted from leaves of *Stevia rebaudiana* and has a relative sweetness 250–300 times higher than sucrose (Gao et al., 2017). Erythritol is a four carbon sugar alcohol, stable at baking temperature, but has to be used with a bulking agent when replacing sucrose for sweetness (Struck et al., 2014). On the other hand, there are different carbohydrate based ingredients such as dietary fibres, gums, or mucilage used as fat replacers. Chia seed (*Salvia hispanica* L.) is especially rich in polyunsaturated fatty acids (25–35%), protein (17–24%), dietary fibre (18–22%), and antioxidants. According to recent studies, chia gel might have potential as a fat or egg replacer due to its dietary fibre content (Felisberto et al., 2015; Zettel and Hitzmann, 2018; Gutiérrez-Luna et al., 2020).

Sugar and fat, as main ingredients of muffins, are being tried to be replaced with natural substances. The aim of this study was to produce possible low-calorie muffins using natural sweetener mixtures and chia gel as sugar and fat replacement, respectively. The effects of replacements on physical and sensory properties of muffins were investigated during shelf life.

## 2. MATERIALS AND METHODS

### 2.1. Materials

Wheat flour (10.9% moisture, 8.98% protein, 0.65% ash) was supplied by Sinangil Food Co. (Konya, Turkey). The other ingredients such defatted milk (Pınar, İzmir, Turkey), egg (Keskinoglu Co., Manisa, Turkey), sunflower oil (Ülker, İstanbul, Turkey), baking powder and caster sugar (Dr-Oetker, İzmir, Turkey), stevia powder sweetener (SPS) (0.85% steviol glycoside RebA, 97.64% erythritol, 1.78% dietary fibre), and chia (*Salvia hispanica* L.) were purchased from local market.

### 2.2. Muffin preparation

Muffins were prepared in 4 different formulations: the control sample (Control), SC is sucrose replacement with SPS, CC is fat replacement with chia gel, and SCC is sucrose and fat replacement with SPS and chia gel, respectively (Table 1).



Table 1. Compositions of cake formulations (g/100 g of wheat flour)

Ingredients	Control	SC	CC	SCC
Wheat flour	100	100	100	100
Egg	90	90	90	90
Defatted milk	60	60	60	60
Sunflower oil	75	75	–	–
Caster sugar	140	–	140	–
Sweetener	–	140	–	140
Chia gel	–	–	75	75
Baking powder	6	6	6	6

Before muffin preparation, chia gel was made by soaking chia seeds with tap water (1:20) at 80 °C for 1 h. Then, the chia gel was separated from the seeds using a filter cloth. The gel was used for CC and SCC formulations.

First, eggs and sugar (or stevia sweetener) were mixed for 3 min at speed 4 using a professional mixer (KitchenAid, USA). Then milk and sunflower oil (or chia gel) were added and it was mixed for 2 min. Flour and baking powder were added onto wet ingredients and it was mixed for 6 min. The batter was poured into muffin pans in equal amounts (50 g) and baked at 170 °C for 25 min in an oven (FIMAK Electric Ovens with Multiple Layers, Turkey). After baking, the muffins were cooled at room temperature for 120 min, then packed into zipper plastic bags and stored at 25 °C for 7 days. All samples were produced in duplicate.

### 2.3. Physical characteristics of muffins

Moisture content was determined according to AACC Method 44-40 (AACC International, 2000).

Water activity ( $a_w$ ) was measured at 20 °C using a Novasina (AW Sprint, TH-500, Switzerland) instrument (Felisberto et al., 2015).

Crumb colour was determined using a colorimeter (Hunter Lab Colour Quest XE, USA). The colour values of  $L^*$  (lightness),  $a^*$  (red-green), and  $b^*$  (yellow-blue) were measured 6 times at different points for each sample from same baking (Gökşen and Ekiz, 2016).

Texture Profile Analysis (TPA) of the muffins were performed using Texture Analyzer (TA-XTi2 Stable Microsystems, Surrey, UK) according to methods described in previous studies (Schirmer et al., 2012).

### 2.4. Sensory analysis

Fifty four (25 males and 29 females) untrained panellists between 23 and 45 years from the Department of Food Engineering (Mersin University, Turkey) participated in the sensory analysis. Samples were evaluated for crumb colour, crust appearance, crumb texture, sweetness, taste, mouthfeel, and overall acceptability. Panellists gave scores on a 9-hedonic scale where 1 = dislike extremely and 9 = like extremely (Rodríguez-García et al., 2014).

### 2.5. Statistical analyses

Differences were evaluated comparing average parameters according to the one-way analysis of variance (ANOVA). The significance was determined using Tukey's comparison test ( $P < 0.05$ ). Tests were performed using SPSS ver. 17 software (IBM SPSS, Armonk, New York, USA).



Table 2. Moisture content and water activity of muffins during storage

	Day	Control	SC	CC	SCC
Moisture content (%)	0	18.83 ± 0.10 <sup>aA</sup>	21.40 ± 0.14 <sup>bA</sup>	29.21 ± 0.29 <sup>cA</sup>	34.81 ± 0.25 <sup>dA</sup>
	1	18.70 ± 0.14 <sup>aA</sup>	19.90 ± 0.15 <sup>bB</sup>	29.00 ± 0.28 <sup>cA</sup>	35.10 ± 0.23 <sup>dA</sup>
	4	18.15 ± 0.12 <sup>aB</sup>	18.40 ± 0.62 <sup>bC</sup>	29.30 ± 0.26 <sup>cA</sup>	35.00 ± 0.37 <sup>dA</sup>
	7	17.40 ± 0.34 <sup>aC</sup>	18.40 ± 0.17 <sup>bC</sup>	29.00 ± 0.29 <sup>cA</sup>	33.30 ± 0.15 <sup>dB</sup>
Water activity (a <sub>w</sub> )	0	0.83 ± 0.01 <sup>aA</sup>	0.84 ± 0.01 <sup>bA</sup>	0.87 ± 0.01 <sup>cA</sup>	0.89 ± 0.01 <sup>dA</sup>
	1	0.82 ± 0.01 <sup>aB</sup>	0.83 ± 0.01 <sup>aA</sup>	0.86 ± 0.01 <sup>bA</sup>	0.88 ± 0.01 <sup>bAB</sup>
	4	0.81 ± 0.01 <sup>aB</sup>	0.82 ± 0.01 <sup>aA</sup>	0.86 ± 0.01 <sup>bA</sup>	0.86 ± .001 <sup>bB</sup>
	7	0.79 ± 0.01 <sup>aC</sup>	0.83 ± 0.01 <sup>bA</sup>	0.86 ± 0.00 <sup>cA</sup>	0.88 ± 0.01 <sup>dA</sup>

Mean values (±standard deviation) in each line with different lowercase letters and in each column with different uppercase letters show significant differences by Tukey's test ( $P < 0.05$ ).

### 3. RESULTS AND DISCUSSION

#### 3.1. Moisture content and water activity

The changes in moisture content and water activity of muffins during storage are shown in Table 2. The moisture content increased significantly ( $P < 0.05$ ) when sucrose was substituted by stevia sweetener, the moisture content of SCC was the highest among formulations. Sucrose prevents moisture loss during baking of cakes due to retention of water (Majzoobi et al., 2018). RebA and erythritol play roles as humectants and bulking agents, so they hold water and prevent it from evaporation during baking. Similar findings for water retention properties for sugar replacers such as erythritol (Lin et al., 2003; Martínez-Cervera et al., 2012), RebA (Majzoobi et al., 2018), and polydextrose (Schirmer et al., 2012) in cakes have been reported.

In addition, chia with its high water holding capacity and gel forming properties provided the increased moisture content of CC and SCC. It can help to achieve desirable sensory characteristics in baked products, such as cakes (Ramos et al., 2017). The soluble fibres in the chia gel interact with water through free hydroxyl groups, thus protecting the moisture in the muffin. Moreover, the fibre associates with starch resulting delay of retrogradation of the cake and providing a slower moisture loss during shelf life (Felisberto et al., 2015).

Water activity provides information about the textural properties, microbial growth, degradation reactions, and staining (Felisberto et al., 2015).

Overall, the control had the lowest a<sub>w</sub> compared to the other samples due to the hygroscopic nature of sugar ( $P < 0.05$ ). The water activity of the muffins was observed to increase significantly with decreasing sucrose and fat contents in different formulations. Similar results were reported by Felisberto et al. (2015), when increased amount of chia mucilage gel as a substitute for vegetable fat increased moisture content. Majzoobi et al. (2018) showed that the use of inulin and RebA as fat and sugar replacement, respectively, was reflected in a significantly higher water activity as a result of the water-binding capacity of inulin and gluten.

#### 3.2. Colour analysis

Colour is one of the most important parameters that determine the consumer acceptance, and the raw materials used in the formulation directly affect the colour of the product.



The effect of replacing sucrose and fat by sweetener and/or chia gel on the colour of the crumb of muffins is summarised in Fig. 1. The addition of chia gel resulted in an increase in the  $L^*$  value of the crumb compared to the control, indicating a lighter appearance. This may be related to the added chia gel being colourless. Ramos et al. (2017) demonstrated that it is desirable for food applications, because the colorations of gel obtained are relatively neutral and allows colouring with addition of other ingredients.

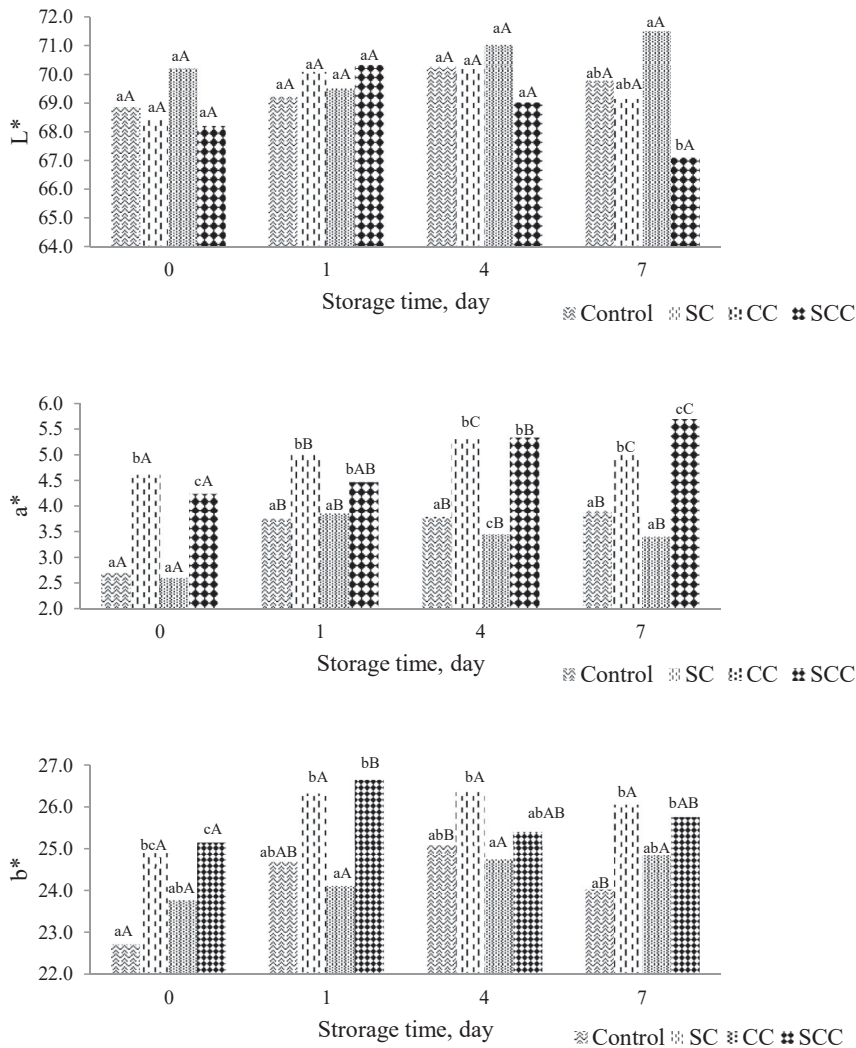


Fig. 1. Crumb colour parameters of muffins during storage. Mean values ( $\pm$ standard deviation) in each day with different lowercase letters and in each sample with different uppercase letters for each parameters show significant differences by Tukey's test ( $P < 0.05$ )



On day 7, SCC showed a decline in lightness in comparison to control, SC, and CC. Lin et al. (2003) reported that the addition of erythritol caused  $L^*$  values to increase in the crumb. The  $a^*$  values decreased in the presence of chia gel and increased significantly in the presence of sweetener ( $P < 0.05$ ), which contains RebA and erythritol, which are known as reducing sugars. The reducing sugars are interacting in Maillard reactions, and thus, may support non enzymatic browning. The similar observation was found by Lin et al. (2003) that with sucrose replacement, the chiffon cake crumb tended to be more reddish in colour compared to the control.

The highest  $b^*$  (yellowness) values were observed in SCC. Thanks to the water retention and interaction between starch and protein features of the chia gel, it has preserved the crumb colour of the muffin for a long time and appeared to behave oil-like during storage. It seems that migration of water from crumb to crust was also prevented (Zettel and Hitzmann, 2018; Aranibar et al., 2019).

### 3.3. Texture profile analysis

Texture profile analysis (TPA), an indicator of physical quality, provides the structural properties of muffin. All samples showed a significant increase in crumb firmness during storage days 0, 1, 4, and 7 ( $P < 0.05$ ) (Table 3). The same phenomenon of increased firmness during storage was identified by Felisberto et al. (2015). The effect of chia gel on firmness may imply that its fibres cause the incorporation of air cells during cake batter and as a result exhibit resistance to mechanical compression.

However, on day 7, there were only significant differences between CC and SCC and control and SC. The chia gel has high water binding capacity due to its soluble fibres, thus, with progressing storage time, it resulted in decrease of moisture content and increase of stiffness in the crumb. Similar results were obtained by Ramos et al. (2017), who explained higher firmness at high temperature application of chia flour suspensions on the effect of gel texture due to high levels of protein interacting with the carbohydrate. Martínez-Cervera et al. (2012) have reported differences in muffin textures when sucrose replacer was used affecting starch gelatinisation.

Table 3. Effect of natural sweetener and chia gel on textural properties of muffin during storage

	Day	Control	SC	CC	SCC
Firmness (N)	0	1.97 ± 0.36 <sup>aA</sup>	2.44 ± 0.71 <sup>aA</sup>	3.82 ± 0.31 <sup>bA</sup>	4.87 ± 0.23 <sup>cA</sup>
	1	2.87 ± 0.28 <sup>aB</sup>	3.80 ± 0.43 <sup>bB</sup>	4.22 ± 0.48 <sup>bcA</sup>	4.50 ± 0.17 <sup>cA</sup>
	4	3.16 ± 0.22 <sup>aB</sup>	4.68 ± 0.55 <sup>aBC</sup>	7.94 ± 0.41 <sup>bB</sup>	9.04 ± 0.25 <sup>cB</sup>
	7	3.59 ± 0.48 <sup>aB</sup>	5.53 ± 0.45 <sup>aC</sup>	8.16 ± 0.67 <sup>bB</sup>	10.62 ± 0.69 <sup>cB</sup>
Chewiness (N)	0	1.41 ± 0.14 <sup>aA</sup>	1.25 ± 0.20 <sup>aA</sup>	2.54 ± 0.24 <sup>bA</sup>	3.16 ± 0.05 <sup>cA</sup>
	1	0.93 ± 0.16 <sup>aB</sup>	0.99 ± 0.08 <sup>aA</sup>	2.80 ± 0.43 <sup>bA</sup>	2.69 ± 0.22 <sup>bA</sup>
	4	1.05 ± 0.14 <sup>aA</sup>	0.83 ± 0.26 <sup>aA</sup>	3.03 ± 0.33 <sup>bB</sup>	3.21 ± 0.16 <sup>bA</sup>
	7	0.77 ± 0.01 <sup>aA</sup>	0.81 ± 0.05 <sup>aA</sup>	3.43 ± 0.05 <sup>bAB</sup>	4.18 ± 0.71 <sup>cB</sup>
Springiness	0	0.86 ± 0.03 <sup>aA</sup>	0.78 ± 0.03 <sup>bA</sup>	0.94 ± 0.03 <sup>cA</sup>	0.95 ± 0.01 <sup>cA</sup>
	1	0.86 ± 0.01 <sup>aA</sup>	0.82 ± 0.02 <sup>bA</sup>	0.95 ± 0.03 <sup>cA</sup>	0.90 ± 0.02 <sup>bcAB</sup>
	4	0.75 ± 0.05 <sup>aB</sup>	0.63 ± 0.03 <sup>bB</sup>	0.88 ± 0.04 <sup>cB</sup>	0.85 ± 0.08 <sup>cB</sup>
	7	0.69 ± 0.03 <sup>aB</sup>	0.62 ± 0.02 <sup>bB</sup>	0.82 ± 0.02 <sup>cB</sup>	0.79 ± 0.05 <sup>acC</sup>

Mean values (±standard deviation) in each line with different lowercase letters and in each column with different uppercase letters for each parameters show significant differences by Tukey's test ( $P < 0.05$ ).



Furthermore, these effects may be mainly related to the differences in water-binding capacities, when the sucrose supplement competes for water with the starch (Gao et al., 2017).

Researchers found similar results stating that fat replacers such as inulin or different fruit fibres (Zahn et al., 2010; Rodríguez-García et al., 2014; Aranibar et al., 2019) and sugar replacer such as erythritol or polydextrose (Martínez-Cervera et al., 2012) increased crumb firmness in cakes.

Therefore, our study indicated that partial replacement of sugar and fat with sweetener and chia gel may provide similar crumb softness and firmness as of the control muffin.

In particular, muffins with sugar replacement (SC) showed the lowest chewiness, however, samples containing both replacements (SCC) had the highest value ( $P < 0.05$ ). During storage, while the chewiness values decreased in the control and SC, they increased in the CC and SCC samples. These results may be associated with higher moisture content retained by chia gel and gained viscoelastic properties, explaining the higher amount of force to be applied while chewing the cake (Zettel and Hitzmann, 2018).

Regarding springiness values, significant differences between chia gel containing muffin samples (CC and SCC) and the control were observed. All samples showed a slight decrease in springiness during storage. Between day 4 and 7, no significant differences in the springiness values of control and SC were displayed, but CC and SCC had different values ( $P < 0.05$ ). The lowest decreased in springiness value was detected for CC until day 7, so it can be said that chia gel as a fat replacer in muffin may be playing a role in delaying stalling. Majzoobi et al. (2018) used inulin and RebA as sucrose and fat replacements in cake formulations, and found a significant decrease in springiness during storage for 3 days. Rodríguez-García et al. (2014) also found that substitution of fat significantly increased springiness of the crumb, and explained this by the increasing strength of the bonds in the three-dimensional network. Similar findings for SC were presented by (Martínez-Cervera et al., 2012), indicating a decrease in the springiness of sugar-free muffins prepared with erythritol.

### 3.4. Sensory analysis

The sensory analysis was performed to evaluate the acceptability of the formulations of muffin (Fig. 2). Overall, the control was preferred and received the highest preference scores in terms of

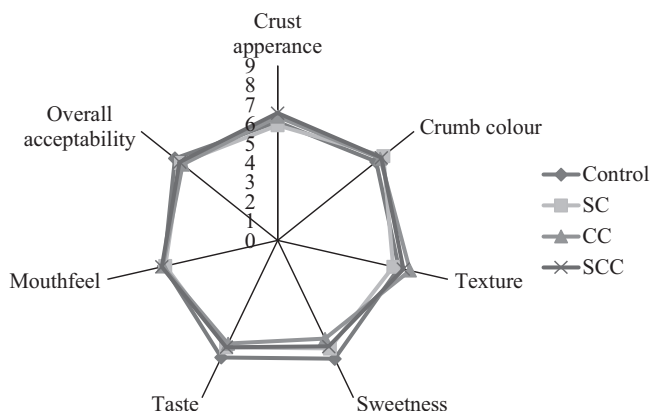


Fig. 2. Effects of sugar and fat replacer on sensory analysis of muffins





sweetness, taste, and overall acceptability. No significant differences regarding desirability were seen between the formulations, but SC appeared to be least appealing. The flat top surface of these muffins seemed to lead to the lowest visual scores by the panellists.

There were no differences in crumb colour among all muffin formulations. In addition, the sensory colour evaluation was accurate when measured instrumentally, while panellists could not identify slight variations that the colorimeter recorded.

Control was significantly more favoured than CC in terms of sweetness ( $P < 0.05$ ). The result is in accordance with previous findings stating that the substitution of sugar with sweetener (erythritol and RebA) in muffins did not affect the sweetness dramatically (Gao et al., 2017).

The texture assessment of the muffins correlates with the instrumental measurement of firmness. CC showed significant differences from SC ( $P < 0.05$ ), a significantly higher firmness of CC was observed. Gao et al. (2017) reported that higher levels of sweeteners had a negative effect on the texture quality of the muffin.

Compared to the overall acceptability of all samples, panellists appreciated SCC more than either SC or CC. No significant differences were found between SCC and control. Control obtained the highest overall acceptability score. The partial replacement of sucrose with RebA has resulted in overall acceptability and similarity to control (Struck et al., 2014). Other studies showed a significant decrease in scores for overall acceptability for the cake with a replacement of fat and sugar with inulin (Rodríguez-García et al., 2014). Therefore, chia gel may be a better fat replacement for bakery products.

## 4. CONCLUSIONS

This research shows that when sweetener and chia gel is used together, muffin with low calories can be obtained. It is best to use both sugar and fat substitutes in the same formulation. When sugar-free and fat-free formulation (SCC) was evaluated, some negative effects on firmness and taste were observed, though for springiness and crust appearance it obtained higher scores. Addition of chia gel to the formulation did not significantly changed lightness value due to the relatively neutral colour of the gel. Further studies are needed to optimise desired texture and consumer acceptability of muffins containing sugar and fat substitution.

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