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Use of chia (*Salvia hispanica* L.) mucilage gel to reduce fat in pound cakes

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A B S T R A C T

Overweight indices have increased in the recent years, and thus the occurrence of non-communicable diseases related to them. The recommendation of fat reduction in food may contribute to reduce the risk of these diseases. Attention has focused on bakery products, such as pound cake, which contains up to 17 g fat/100 g product. A novel ingredient, chia seed (*Salvia hispanica* L.), has been studied for its high water-absorbing and viscous mucilaginous external layer, in order to evaluate its potential as fat substitute in bakery products. We investigated the effects of the replacement of 25, 50, 75 and 100 g/100 g of vegetable fat by chia mucilage gel (CMG) on the technological properties of pound cakes. CMG was produced by rehydration with water of lyophilized chia mucilage (LCM). Replacement of vegetable fat by CMG did not significantly alter the specific volume, symmetry, uniformity, moisture and water activity (a_w) of the cakes. Color parameters, as well as crumb firmness of cakes, were influenced by higher levels of fat replacement with CMG. We concluded that the replacement of up to 25 g/100 g of fat by CMG is technologically feasible in pound cakes, with no significant alterations on their quality characteristics.

1. Introduction

Fat reduction in food is a major concern in our days, as market demands increase for lower fat products. This is related to indices showing a duplication of the population with overweight and obesity in the last 30 years, accounting in 2008 more than 1400 million adults (WHO, 2014). Obesity may be related to other non-communicable diseases (Grundy, 2004). Fat substitution by other ingredients is a great challenge, with special focus in bakery products, as they can contain elevated levels of fat.

Pound cakes are consumed everywhere, and can contain up to 17 g/100 g fat in the product. Fat provides several advantages to pound cakes, such as higher volume and softness in the final product, due to a higher air incorporation during batter preparation and inhibition of gas-bubble coalescence, leading to a finer and softer crumb structure (Bennion & Bamford, 1997; Bobbio & Bobbio, 2003). In addition, fats and emulsifiers delay starch gelatinization by retarding water transfer into the starch granule, by the formation of complexes between polar lipids and amylose during baking, thus improving the tenderness, moisture content and flavor of the cakes, extending shelf-life (Bennion & Bamford, 1997; Luna Pizarro, Almeida, Sammán, & Chang, 2013). Thus, several problems appear when fat content is reduced in pound cakes, such as lower volume, denser crumb, firmer eating qualities, and loss of flavor, compared to conventional cakes (Cauvain & Young, 2006). It is a current challenge to provide palatable and marketable products, while reducing fat in pound cakes.

Over the years, different ingredients have been used for replacement of fat in foods, such as gums, fibers or mucilage. Chia mucilage has been recently studied as a possible fat replacer. Chia seed (*Salvia hispanica* L.) was an important staple food for Mesoamerican cultures in pre-Columbian times, surpassed only by corn and beans in significance (Luna Pizarro et al., 2013; Reyes-Caudillo, Tecante, & Valdivia-López, 2008). It was initially cultivated in Mexico, being now spread to other regions. The evaluation of its properties and possible uses has shown a high nutritional value,

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especially due to its fiber content (Bushway, Belyea, & Bushway, 1981; Ixtaina, Nolasco, & Tomás, 2008; Reyes-Caudillo et al., 2008).

Special interest has been awakened by chia mucilage, which is composed of neutral sugars, indicating the presence of diverse carbohydrates on its structure. Lin, Daniel, and Whistler (1994) proposed a structure of a tetrasaccharide with 4-*O*-methyl-α-D-glucoronopyranosyl residues occurring as branches of β-D-xylopyranosyl on the main chain. Due to its structure, chia mucilage acts like soluble fiber and it is known to have excellent water holding properties. Thus, chia mucilage might provide hydration, viscosity development and conservation of freshness, especially for baked goods, therefore, presenting a potential as fat substitute (Vázquez-Ovando, Rosado-Rubio, Chel-Guerrero, & Betancur-Ancona, 2009).

In this study our purpose was to extract and characterize chia mucilage, prepare chia mucilage gel (CMG), and evaluate the effects of its incorporation on the technological quality of pound cakes with the reduction of 25, 50, 75 and 100 g/100 g of fat.

2. Material and methods

2.1. Material

The wheat flour used was type 1 (Nita, Santos, Brazil), blended with corn starch (16 g/100 g), in order to reduce flour strength (Amidex 3001—Corn Products, Mogi Guaçu, Brazil). This blend contained 11.03 g/100 g moisture, 11.84 g/100 g protein, 0.89 g/100 g lipids, 0.53 g/100 g ash, 1.87 g/100 g dietary fiber and 75.71 g/100 g carbohydrates. Farinograhic water absorption, stability and mixing tolerance index of the blend were 55.87 g/100 g, 15.8 min and 38.33 Brabender Unit (BU), respectively, determined through AACC method 54-21.01 (AACC, 2010); alveographic resistance to extension (P), extensibility (L) and the dough deformation energy (W) of the blend were 82.97 mm, 36.67 mm and 135.03 10^{-4} J, respectively, determined through AACC method 54-30.02 (AACC, 2010).

The chia seeds were kindly donated by R & S Blumos (Campinas, Brazil). The vegetable fat used was Pan Advance S550 (Cargill Agrícola S/A, Itumbiara, Brazil). Additional ingredients were obtained at the local market: sugar (Guarani, Olímpia, Brazil), baking powder and emulsifier (Emulzint, Jundiaí, Brazil), whole milk powder (Piracanjuba, Bela Vista de Goiás, Brazil) and whole liquid pasteurized eggs (Fleischmann, Sorocaba, Brazil).

2.2. Methods

2.2.1. Chia mucilage extraction

The chia mucilage was obtained according to Muñoz, Cobos, Diaz, and Aguilera (2012), with modifications at the end of the process. The optimum extraction process was performed at a temperature of 80 °C with a seed: water ratio of 1:40. The mixtures were stirred and hydrated for 2 h. Then, the aqueous suspension was separated from the chia seed with an M6 227/3498 brush depulper (Sterling Electric Motors, California, USA). Finally, the aqueous suspension was filtered (Tyler 20 mesh, 0.85 mm screen), concentrated in a vacuum jacketed kettle (Groen MFG, Illinois, USA), freeze-dried in an LP 820 lyophilizer (São Paulo, Brazil) and stored in hermetically sealed plastic packaging. The yield was 7.86 g of lyophilized chia mucilage/100 g of chia seeds.

2.2.2. Physicochemical characteristics of chia seeds and mucilage

The moisture, protein, lipid, and ash contents of the chia seeds and lyophilized chia mucilage (LCM) were determined by the following AACC methods: 44-15.02, 46-13.01, 30-25.01 and 08-01.01 (AACC, 2010), respectively. Total dietary fiber was determined according to AACC method 32-07.01 (AACC, 2010), reducing sample weight to 0.1 g because of the increase in viscosity caused by mucilage in the samples, as cited by Mañas, Bravo, and Saura-Calixto (1994) and Reyes-Caudillo et al. (2008). The digestible carbohydrate content was calculated by difference.

Instrumental color analysis was performed on LCM using a CR 410 colorimeter (Konica Minolta, Tokio, Japan), with a 50 mm port size, illuminant D65, SCI and a 10° standard observer angle. The LCM color was evaluated by the tri-stimulus CIELab color space method, determining the lightness (L*), redness (a*) and yellowness (b*) values.

2.2.3. Chia mucilage technological characterization

The LCM was characterized by its water holding (WHC) and oil holding capacity (OHC), according to Vázquez-Ovando et al. (2009), with modifications.

2.2.4. Cake preparation

The cake formulation showed in Table 1 was based and balanced according to Montenegro (2011), Bedoya-Perales and Steel (2014) and Bennion and Bamford (1997). Vegetable fat (in the reference formulation-RF) was replaced by CMG at different levels of substitution: 25, 50, 75 and 100 g/100 g. Before cake preparation, CMG was prepared by hydrating LCM with tap water (3 g/100 g aqueous solution), mixing with a Walita mixer (Philips—RI 1341, Varginha, Brasil) and leaving to rest for 30 min.

For cake preparation, sugar, fat and emulsifier were initially creamed by mixing for 10 min at high speed (level three speed) in a K45SS high-speed planetary mixer (Kitchenaid, St. Joseph, USA). The eggs were then added to cream phase and mixed for 5 min at high speed (level three speed) in an LA planetary mixer (Amadio, São Paulo, Brazil), with 20 L capacity.

The wheat flour, corn starch, salt, baking powder and sodium propionate were then added and mixed for 5 min at low speed (level one speed). Finally, the reconstituted whole milk, water and CMG were added and mixed for 1 min at low speed, then 1 min at high speed and 1 additional min at low speed to obtain a uniform batter. The batter density was measured at this point.

The batter (260 g), at approximately 26 °C, was then transferred to paper molds (16 × 7 × 4.5 cm) and placed in a hearth oven, with forced air circulation, Vipinho 0448 (Perfecta, Curitiba, Brazil), at 170 ± 2 °C for 25 min. After cooling to room temperature (25 °C/2 h), the cakes were sprayed with a sorbic acid alcoholic solution (preservative) and packaged in polyethylene plastic bags. Cake processing was carried out three times on different days. Cake samples were stored at room temperature for periodical evaluation.

2.2.5. Technological characteristics of the cakes

The specific volume, symmetry and uniformity indices were determined 1 day after the cakes were prepared. The cake crumb color, moisture content, water activity (a_w) and crumb firmness were evaluated after 1, 7 and 14 days of storage.

The specific volume was calculated as the ratio of apparent volume to weight. Apparent volume (mL) was measured by seed displacement, according to AACC method 10-05.01 (AACC, 2010), and weight (g) was determined using a PB 3002 semi-analytical balance (Mettler Toledo, Greifensee, Switzerland). Cake symmetry and uniformity indices were calculated according to AACC method 10-90.01 (AACC, 2010).

Instrumental color analysis was performed directly on central slices from cakes, on days 1, 7 and 14 of storage, using the same equipment and parameters as for mucilage color evaluation.

Cake moisture content was determined by AACC method 44-15.02 (AACC, 2010). Water activity (a_w) was measured directly in a CX-2T hygrometer (Decagon, Pullman, EUA), at room temperature (25 °C).

Table 1
Cake formulations with the replacement of vegetable fat by chia mucilage gel (wheat flour + corn starch basis).

Ingredients	RF	CMG-25	CMG-50	CMG-75	CMG-100
Wheat flour	84	84	84	84	84
Corn starch	16	16	16	16	16
Sugar	75	75	75	75	75
Eggs	40	40	40	40	40
Baking powder[a]	5	5	5	5	5
Reconstituted whole milk powder[b]	30	30	30	30	30
Vegetable fat	30	22.5	15	7.5	0
Chia mucilage gel (CMG)[c]	0	7.5	15	22.5	30
Emulsifier gel[d]	2	2	2	2	2
Sodium propionate	1.1	1.1	1.1	1.1	1.1
Salt	1.0	1.0	1.0	1.0	1.0
Water[e]	55	30.83	34.37	35.83	35.08
Total water added (water + water in reconstituted whole milk + water in chia mucilage gel)	75	58.11	68.92	77.66	84.18

RF: reference formulation; CMG-25, CMG-50, CMG-75 and CMG-100: formulations with 25, 50, 75 and 100% substitution of vegetable fat by chia mucilage gel, respectively.
[a] Disodium diphosphate (INS450i), sodium hydrogen carbonate (INS 500ii) and calcium dihydrogen phosphate (INS 341i).
[b] 10 g whole milk powder/20 g water.
[c] CMG preparation: 3 g of lyophilized mucilage/100 g aqueous solution, leaving to rest for 30 min.
[d] Polyglycerol esters of fatty acids (INS 475), polyoxyethylene (20) sorbitan monooleate (INS 433) and sorbic acid (INS 200).
[e] Adjusted to keep batter density constant at 1.04 g/mL.

Crumb firmness was evaluated by AACC method 74-09.01 (AACC, 2010), using a TA-XT2i texture analyzer (Texture Technologies; Godalming/Surrey, UK) with 25 kg capacity, SMS P/36R mm aluminum cylindrical probe and stand HDP/90, with the following parameters: pre-test speed of 1.0 mm/s, test speed of 1.0 mm/s, post-test speed of 10.0 mm/s and 2.5 mm of distance. For the test, 10 mm-thick slices from cakes were sliced transversely using a FP353 slicer (G. Paniz, Caxias do Sul, Brazil).

2.2.6. Statistical analysis

Physicochemical characteristics of chia seeds and LCM were determined in triplicate, except for LCM color that was on six replicates. For cakes, three process replicates were made for each formulation (RF, CMG-25, CMG-50, CMG-75 and CMG-100). Specific volume, symmetry and uniformity indices, moisture content and water activity (a_w) were measured in triplicate for each process replicate. Instrumental color and texture were evaluated on six replicates for each process replicate. Analysis of variance (ANOVA) of the means was performed using the SAS statistical software, version 9.4 (SAS Institute Inc., Cary, USA), at a significance level of 5%. When significant, the Tukey's test was used to determine statistical differences between means.

3. Results and discussion

3.1. Chia seeds and mucilage

Table 2 shows the proximate compositions of chia seeds and LCM. Chia seeds presented an elevated content of proteins and lipids, similar to those found by other authors (Ayerza & Coates, 2004; Bushway et al., 1981; Capitani, Ixtaina, Nolasco, & Tomás, 2013; Earle et al., 1960). However, the fiber content of this chia variety is lower than that reported by Ayerza and Coates (1999) and Bushway et al. (1981), who found 22.1 g/100 g and 18.00 g/100 g, respectively.

Similar results of LCM for protein and lipid contents were obtained by Capitani et al. (2013), but the ash content obtained was higher, probably caused by the mucilage extraction conditions, due to the force applied by the brushes on the seeds, causing the removal of the seed outer layers and increasing the impurities of the mucilage.

The LCM instrumental color values were 66.41 ± 0.26 for lightness (L*), 3.30 ± 0.04 for redness (a*) and 12.96 ± 0.04 for yellowness (b*), visualized as a beige to grey color (Fig. 1).

Water holding capacity (WHC) is the ability of a moist material to retain water when subjected to an external centrifugal gravity force or compression (Vázquez-Ovando et al., 2009). LCM exhibited a WHC of 57.33 ± 1.24 g water/g LCM, a higher value than 15.4 g water/g chia fiber-rich fraction, as reported by Vázquez-Ovando et al. (2009). This is explained by the fact that they obtained a fiber-rich fraction (56.46 g/100 g of dietary fiber, d.b.) with an elevated content of insoluble dietary fiber, which may not retain so much water as the mucilage obtained in the present study. The WHC measured in this study is also superior to other fibrous residues of some fruits (7.2 g water/g sample of passion fruit fiber-rich fraction and 8.39 g water/g sample of orange fiber), found by Cruz-Salazar (2002) and Tamayo and Bermudez (1998), cited by Vázquez-Ovando et al. (2009). This is due to the affinity of fiber with water (López et al., 1996).

In this study, the LCM presented a lower oil holding capacity (OHC) (12.97 ± 1.90 g oil/g sample) compared to the WHC (57.33 ± 1.24 g water/g LCM), nevertheless this value was higher than the OHC of the fiber-rich fraction of chia analyzed by Vázquez-Ovando et al. (2009) (2.02 g oil/g sample).

Table 2
Proximate composition of chia seeds and lyophilized chia mucilage.

Components	Chia seeds (g/100 g)	Lyophilized chia mucilage (g/100 g)
Moisture	6.52 ± 0.05	5.74 ± 0.09
Protein	24.36 ± 0.19	11.62 ± 0.10
Lipids	34.09 ± 0.04	3.20 ± 0.06
Ash	3.70 ± 0.11	15.60 ± 1.40
Total dietary fiber	14.78 ± 0.70	37.35 ± 2.67
Digestible carbohydrates	16.55	26.49

3.2. Pound cakes

3.2.1. Specific volume, symmetry and uniformity indices

The specific volume (Table 3) of the cakes ranged from 2.33 to 2.64 cm^3/g. CMG-25 presented the highest value, which was significantly different from the other formulations. Volume is a very important quality for cakes, which strongly influences consumer preference, and is directly related to the type and amount of shortening used.

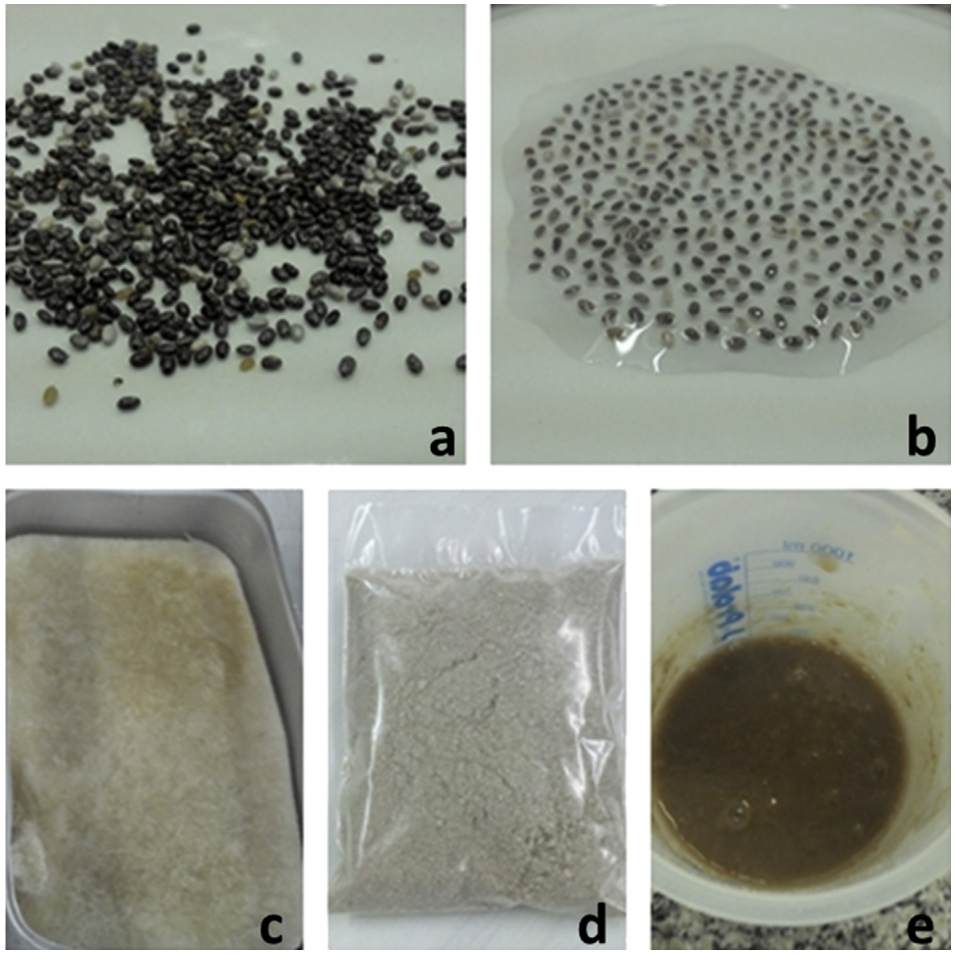

Fig. 1. Chia seeds and chia mucilage. a – chia seeds; b – hydrated chia seeds; c – lyophilized chia mucilage; d – grinded lyophilized chia mucilage; e – chia mucilage gel (CMG).

The specific volume values obtained were similar to those found by Luna Pizarro et al. (2013), who incorporated 0–30 g of whole chia flour/100 g flour mixture in cakes. Bedoya-Perales and Steel (2014), who worked varying fat percentages in pound cakes, also obtained specific volumes close to the values found in this work for formulations containing 20 and 40 g of fat/100 g of flour, due to formulations adjustment by mass balance.

In the present study, the replacement of fat by CMG, even at levels above 50 g/100 g did not cause a significant difference in the specific volume when compared with reference formulation. Furthermore, a higher specific volume was obtained with the lowest level of vegetable fat substitution (CMG-25), compared to the reference cake.

Table 3
Specific volume, symmetry and uniformity indices of pound cakes on day 1.

Formulations	Specific volume (cm^3/g)	Symmetry index (cm)	Uniformity index (cm)
RF	2.33 ± 0.14^b	5.60 ± 0.13^a	-0.2 ± 0.52^a
CMG-25	2.64 ± 0.07^a	5.58 ± 0.72^a	0.0 ± 0.43^a
CMG-50	2.48 ± 0.02^{ab}	6.33 ± 1.04^a	0.0 ± 0.00^a
CMG-75	2.35 ± 0.10^b	5.50 ± 1.80^a	0.5 ± 0.50^a
CMG-100	2.35 ± 0.15^b	6.25 ± 0.75^a	-0.1 ± 0.38^a

RF: reference formulation; CMG-25, CMG-50, CMG-75 and CMG-100: formulations with 25, 50, 75 and 100% substitution of vegetable fat by chia mucilage gel, respectively. Means followed by the same lowercase letters in the same column did not differ ($p < 0.05$) by the Tukey test.

The symmetry and uniformity indices did not present significant differences between formulations (Table 3 and Fig. 2). This suggests the ability of chia mucilage to replace the vegetable fat, without loss in these technological properties of the cake.

The symmetrical development of the batter during baking is an important characteristic in cakes; in this case, a peak was expected in the center of the cake, due to the rise that occurs during baking. Thus, symmetry index values should be greater than zero, indicating a higher center than its extremities (Almeida, Marangoni, & Steel, 2013). All cakes presented positive symmetry indices. However, we obtained higher values than reported in the literature, and also greater variations for cakes produced with CMG, which could be caused by more viscous batters.

However, the uniformity index, which measures the difference between the heights of the two extremes of the cake, must be as close to zero as possible, indicating uniform growth of the batter and structural maintenance of the cake during baking and cooling. These parameters determine consumer acceptance of the product.

Borneo, Aguirre, and León (2010) prepared cakes adding 25, 50 and 75 g of chia gel/100 g of eggs or oil, and they observed a reduction of the specific volume of the final cake with substitution levels above 50 g/100 g, meaning that the product was less aerated and denser, however the symmetry and uniformity indices did not present significant change. Comparing these results of replacing chia gel and LCM, a great potential of LCM as fat replacer in pound cakes is seen, because there was no reduction of specific volume of cakes in all the substitutions levels (up to 75 g/100 g).

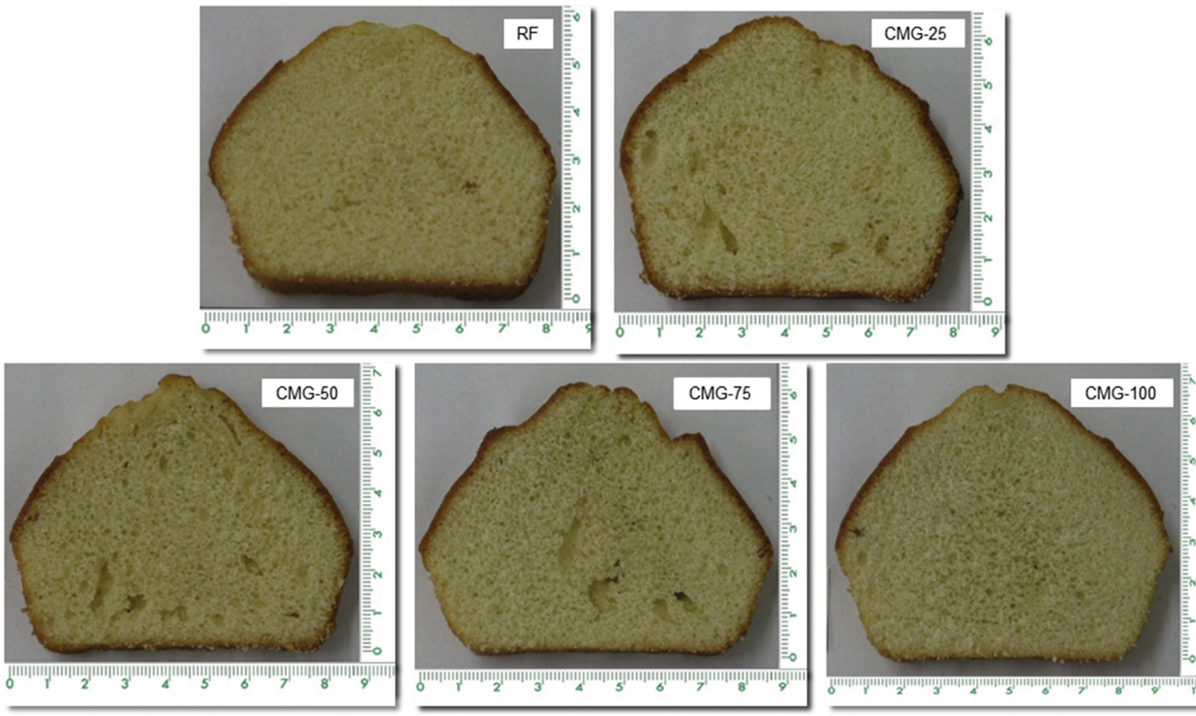

Fig. 2. Slices of cakes evaluated. RF: reference formulation; CMG-25, CMG-50, CMG-75 and CMG-100: formulations with 25, 50, 75 and 100 g/100 g substitution of vegetable fat by chia mucilage gel, respectively.

3.2.2. Color

Color is one of the most important characteristics in the appearance of a cake, since it contributes to consumer preference in relation to the product. Table 4 shows the values for L*, a* and b*.

Even though the crumb does not undergo the Maillard reaction, it is affected by the ingredients in the formula (Akesowan, 2007). On day 1 there was a significant difference in lightness (L*) of the reference formulation (RF) and the formulation with total replacement of fat (CMG-100). On day 7, the replacement of 75 and 100 g/100 g of fat (CMG-75 and CMG-100) presented a reduction of lightness, in comparison to the reference formulation. On day 14, the differences became significant for the replacement of more than 50 g/100 g of fat (CMG-50, CMG-75 and CMG-100).

This behavior is directly related to the low value of L* which lyophilized chia mucilage presented (66.41 ± 0.26) and its grayish color, as well as the brownish color of the CMG. When compared with standard color values for vegetable margarine ($L^* = 81.81$, $a^* = -2.26$ and $b^* = 36.48$ (Idris, deMan, Tang, & Chong, 1996)), the impact of gel color on cakes is explained and expected to darken with greater contents of CMG.

No statistical differences were observed for parameter a* (redness) with the reduction of fat and increase of CMG, but parameter b* (yellowness) showed a decrease with an increased incorporation of CMG, and the lowest values were observed in the formulation with total substitution of vegetable fat (CM-100).

During the shelf-life, no alteration in instrumental color parameters were observed, except for a significant reduction in b* for the reference formulation (RF).

Luna Pizarro et al. (2013) observed a reduction in the values of all color parameters evaluated in cakes with the addition of whole chia flour, probably because of its own color, making the crumb color darker. Similar results were also observed by Borges, Pirozi, Vidigal, de Paula, and Silva (2013) when adding quinoa flour in cakes.

Table 4
Crumb color of pound cakes during their shelf-life.

Color parameter	Formulations					
	Days shelf life	RF	CMG-25	CMG-50	CMG-75	CMG-100
L*	Day 1	78.26 ± 1.36^{aA}	77.01 ± 1.27^{aAB}	75.50 ± 1.81^{aAB}	74.42 ± 1.28^{aAB}	73.97 ± 1.54^{aB}
	Day 7	77.97 ± 1.08^{aA}	77.77 ± 1.34^{aA}	74.99 ± 0.41^{aAB}	74.63 ± 0.69^{aB}	74.57 ± 1.76^{aB}
	Day 14	77.45 ± 0.48^{aA}	77.72 ± 0.81^{aA}	74.93 ± 0.40^{aB}	74.85 ± 0.42^{aB}	74.40 ± 1.07^{aB}
a*	Day 1	0.0993 ± 0.3^{aA}	0.1393 ± 0.3^{aA}	0.3287 ± 0.2^{aA}	0.4293 ± 0.2^{aA}	0.5467 ± 0.1^{aA}
	Day 7	0.6547 ± 0.5^{aA}	0.3500 ± 0.4^{aA}	0.6073 ± 0.2^{aA}	0.6173 ± 0.2^{aA}	0.6047 ± 0.0^{aA}
	Day 14	0.9420 ± 0.4^{aA}	0.5553 ± 0.3^{aA}	0.7407 ± 0.2^{aA}	0.6787 ± 0.1^{aA}	0.5987 ± 0.1^{aA}
b*	Day 1	27.51 ± 0.38^{aA}	26.22 ± 0.88^{aA}	26.07 ± 0.45^{aAB}	24.45 ± 0.58^{aBC}	23.49 ± 0.69^{aC}
	Day 7	26.22 ± 0.30^{bA}	25.03 ± 0.79^{aAB}	24.95 ± 1.11^{aAB}	24.27 ± 1.71^{aAB}	22.16 ± 0.98^{aB}
	Day 14	25.97 ± 0.30^{bA}	25.19 ± 0.79^{aA}	25.01 ± 1.07^{aA}	23.01 ± 0.68^{aB}	21.71 ± 0.41^{aB}

RF: reference formulation; CMG-25, CMG-50, CMG-75 and CMG-100: formulations with 25, 50, 75 and 100% substitution of vegetable fat by chia mucilage gel, respectively. Means followed by the same lowercase letters in the same column, for the same parameter, did not differ ($p < 0.05$) by the Tukey test. Means followed by the same uppercase letters in the same line did not differ ($p < 0.05$) by the Tukey test.

3.2.3. Moisture content

As shown in Table 5, for all pound cake formulations the moisture content did not present significant differences over the shelf-life, within the same formulation.

Moisture content in foods is indicative of quality, and moistness is one of the desirable sensory characteristics in baked products, as it is usually related to a soft product (Dadkhah, Hashemiravan, & Seyedain-Ardebili, 2012). Cake moisture contents did not show significant differences on day 1, except between formulations CMG-25 and CMG-100, the latter presenting higher moisture content, probably due to its complete replacement of fat by CMG. This level of replacement introduces a higher quantity of water into the batter and the higher dietary fiber content can retain water in the food matrix, through chemical interactions (Moraes et al., 2010). This same phenomenon is repeated on days 7 and 14 between formulation CMG-25 and formulations CMG-75 and CMG-100.

Additionally, none of the formulations presented a significant loss of moisture on day 7 or 14 of storage. Thus, the cakes presented good water retention capacity because of the presence of dietary fiber (Bennion & Bamford, 1997; Luna Pizarro et al., 2013).

The high levels of dietary fiber in chia mucilage (Table 2) help maintain the moisture in the product, because of the numerous free hydroxyl groups in fiber which can form hydrogen bonds with water (Oakenfull, 2001). Furthermore, interactions between the fiber and starch can delay starch retrogradation and avoid the loss of moisture during storage. This point is very important for baked products, because with no fat to prevent moisture loss they would dry out (Bennion & Bamford, 1997).

Additionally, the packaging material used to store the cakes is a barrier to moisture, which allows only a redistribution of water from the crumb in the direction of the crust.

3.2.4. Water activity (a_w)

The measurement of water activity has been useful for predicting the stability and safety of foods, with respect to microbial growth, deterioration reactions, and chemical and physical properties (Fontana, 1998). Table 5 presents the water activity of the cake formulations without significant differences over the shelf-life, within the same formulation. A decrease in water activity (a_w) of the crumb during storage was expected due to the water migration from the crumb to the crust, but this did not occur.

When comparing the behavior of the different formulations, on each day, significant differences could be observed. On day 1, formulation CMG-100 presented a higher a_w, because of the greater quantity of total water added to the batter.

All formulations presented critical stability over the shelf-life, since they showed values of a_w exceeding 0.887, conducive to the development of some positive and negative gram bacteria and yeast (Jay, 2005). Care must be taken with the quality of the raw materials and the hygienic conditions during and specially after processing. Depending on the required shelf-life, the use of permitted preservative agents is also a strategy to avoid microbiological growth.

Similar results were observed by Bedoya-Perales and Steel (2014), when comparing the effect of different concentrations of maltogenic α-amylase and fat on technological and sensory quality of cakes.

3.2.5. Texture

Texture is a very important quality attribute for baked goods and can determine sensorial shelf-life. It is known that during storage, even under conditions that prevent moisture loss, cakes may lose freshness and become firmer, especially at temperatures between 15 and 20 °C (Bedoya-Perales & Steel, 2014; Cauvain & Young, 2006), probably due to starch retrogradation, interaction between starch and protein, and water migration (Wilderjans, Luyts, Brijs, & Delcour, 2013). As fat is an ingredient with a positive effect on product texture by keeping cakes softer for a longer period of time, the effects of its reduction must be closely evaluated.

Table 5 shows the values for cake firmness on storage days 1, 7 and 14, which increased over shelf-life. The same tendency of the increase of firmness during storage was observed in other studies. Luna Pizarro et al. (2013) obtained an increase of firmness during storage (5.34–8.89 N), when adding whole chia flour (WCF) in pound cakes. According to Sudha, Baskaran, and Leelavathi (2007), cakes prepared by replacing wheat flour at levels of 10, 20 and 30 g/100 g by apple pomace yielded harder texture with increasing levels of pomace (11.28–14.32 N).

On every day of shelf-life, a significant increase in firmness was observed as the level of incorporation of CMG increased above 50 g/100 g of replacement of fat. An exception was observed on day 1, when CMG-100 was not statistically different from the reference formulation (RF), probably due to the greater quantity of water in CMG-100.

The behavior of formulation CMG-100 can be explained by the fact that the mucilage has a high capacity to retain water, which may have positively influenced the texture of the cakes (increasing softness). However, throughout the shelf-life this water was lost, which justifies the increase in the firmness of the samples. In the case of formulations CMG-50 and CMG-75, the reduction of vegetable fat resulted in a lower aeration capacity, poorer crumb structure and, consequently, a less tender cake crumb and greater firmness.

Moreover, on day 7, there was a significant difference between formulations CMG-75 and CMG-100 and the reference (RF), and on day 14, between formulations CMG-50, CMG-75 and CMG-100 and the reference (RF). This shows that, as time progressed, the importance of fat to retard crumb firming was more evident.

Table 5
Moisture content, water activity and crumb firmness of pound cakes during their shelf-life.

		RF	CMG-25	CMG-50	CMG-75	CMG-100
Moisture content (g/100 g)	Day 1	28.74 ± 2.54^{abA}	25.24 ± 1.55^{bA}	27.97 ± 0.76^{abA}	29.18 ± 0.59^{abA}	29.69 ± 1.71^{aA}
	Day 7	26.63 ± 0.54^{abA}	23.29 ± 0.83^{bA}	26.24 ± 0.13^{abA}	28.15 ± 1.61^{aA}	29.07 ± 2.63^{aA}
	Day 14	26.07 ± 0.41^{abA}	23.23 ± 0.55^{bA}	25.93 ± 0.71^{abA}	28.34 ± 1.61^{aA}	28.83 ± 2.74^{aA}
Water activity (a_w)	Day 1	0.90 ± 0.01^{abA}	0.87 ± 0.02^{bA}	0.89 ± 0.02^{abA}	0.91 ± 0.01^{abA}	0.91 ± 0.01^{aA}
	Day 7	0.89 ± 0.01^{abA}	0.87 ± 0.01^{bA}	0.89 ± 0.01^{abA}	0.90 ± 0.01^{aA}	0.90 ± 0.01^{aA}
	Day 14	0.89 ± 0.00^{aA}	0.87 ± 0.01^{bA}	0.89 ± 0.01^{abA}	0.90 ± 0.01^{aA}	0.91 ± 0.01^{aA}
Force (N)	Day 1	8.88 ± 0.04^{bB}	10.19 ± 0.65^{abB}	12.62 ± 0.43^{aC}	13.58 ± 1.26^{aB}	12.35 ± 1.38^{abB}
	Day 7	13.15 ± 2.05^{cAB}	14.29 ± 2.19^{bcAB}	17.72 ± 0.45^{abcB}	23.78 ± 1.01^{aA}	21.16 ± 2.77^{abA}
	Day 14	16.00 ± 2.06^{bA}	19.32 ± 0.52^{bA}	24.77 ± 0.08^{aA}	28.67 ± 1.98^{aA}	26.12 ± 0.03^{aA}

RF: reference formulation; CMG-25, CMG-50, CMG-75 and CMG-100: formulations with 25, 50, 75 and 100% substitution of vegetable fat by chia mucilage gel, respectively. Means followed by the same lowercase letters in the same line, for the same parameter, did not differ ($p < 0.05$) by the Tukey test. Means followed by the same uppercase letters in the same column, for the same parameter, did not differ ($p < 0.05$) by the Tukey test.

The replacement of fat up to 25 g/100 g by CMG in pound cakes presented no significant difference compared to the reference formulation for the parameter firmness, until day 14.

The results show that 25 g/100 g of fat substitution in pound cakes is feasible, as we obtained a product with unaltered technological characteristics, which can be marketed with a specific "fat reduction" functional claim.

As the vegetable fat was substituted by chia mucilage gel (CMG), prepared by hydrating lyophilized chia mucilage (LCM) with tap water (3 g/100 g aqueous solution), and due to the low fat content in LCM (3.20 g/100 g – Table 2), its contribution to the final fat content was not significant. Thus, the reduction of fat was effectively of 25 g/100 g in the final product.

Additionally, cakes were produced with no requirement of additives or other ingredients, besides CMG, to supply the reduction of fat, which can also be related with the concept of "clean label". Further studies should be done characterizing the proximal composition and sensory acceptance of the fat-reduced pound cake, in comparison to the reference.

4. Conclusions

This study showed CMG as a new ingredient as fat replacer in cakes. New processes for obtaining CMG can be developed, since it can be a by-product of the process of extraction of oil or bioactive compounds from chia seeds, in the same way that different oilseeds and legumes undergo modern processing techniques for oil extraction and obtention of by-products for human consumption.

CMG was used effectively as a fat replacer, as results indicate that formulations with up to 25 g/100 g of fat substitution presented technological characteristics similar to the reference, and maintained them during the storage. The great importance of this ingredient is that cakes were obtained with no requirement of additives or other ingredients to supply the reduction of fat, on structure and texture of cakes. This is an important advantage, for the use of a clean label claim when the product is marketed.

However, levels superior to 25 g/100 g of fat substitution should be carefully formulated, since color and texture of the product may be negatively affected.

Further studies are recommended to determine the applicability of this novel ingredient as fat substitute in other bakery products.

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