Effects of replacing fat by betaglucans from *Ganoderma lucidum* on batter and cake properties

Jairo Lindarte Artunduaga¹ · Luis-Felipe Gutiérrez¹

Revised: 4 November 2018 / Accepted: 7 November 2018 / Published online: 4 December 2018
© Association of Food Scientists & Technologists (India) 2018

Abstract The aim of this study was to investigate the effects of replacing vegetable fat at different concentrations (20, 30, 40 and 50%) by betaglucans from *Ganoderma lucidum* (β GGL), on the physical properties of cake batters, and on the quality of the resultant cakes. The addition of β GGL significantly affected the specific gravity, the flow properties and the color of the batter formulations. The fat-replacing led to a slight reduction in the volume of cakes, because fewer air bubbles were incorporated into the batter samples as the concentration of β GGL increased. The hardness of the cakes significantly increased during storage as the amount of β GGL increased. The fat-reduced cakes displayed similar color, moisture content, and water activity than the control cake samples. However, the crumb microstructure was affected by the addition of β GGL, as revealed by the scanning electron micrographs. The fat-reduced cakes containing 40% β GGL showed a general sensorial acceptance of 97%, as indicated by untrained panelists. These results suggest that β GGL could be used as fat replacers for improving the nutritional value of batter cakes.

Keywords Bakery · Betaglucans · Batter cakes · Fat-reduced foods · *Ganoderma lucidum*

Electronic supplementary material The online version of this article (<https://doi.org/10.1007/s13197-018-3507-1>) contains supplementary material, which is available to authorized users.

✉ Luis-Felipe Gutiérrez
lfgutierrez@unal.edu.co

¹ Instituto de Ciencia y Tecnología de Alimentos (ICTA),
Universidad Nacional de Colombia Sede Bogotá, Carrera 30
No. 45-03, Edificio 500A, Bogotá, DC 111321, Colombia

Introduction

Fat-reduced foods are gaining importance within the market of functional foods, because the consumers are more conscientious about the relationship between the fat intake and obesity, and since obesity has been related to a variety of health problems, such as cardiovascular diseases, diabetes, and cancer (Meleady 2018).

Fat plays an important role on the physicochemical and sensory properties of baked goods, because it improves their volume and softness, due to a greater incorporation of air during the creaming process, and to the inhibition of the gas-bubble coalescence, leading to a finer and softer structure of the crumb (Bennion and Bamford 1997). Moreover, the fat contributes to extend the shelf-life of the baked products, since it delays the starch gelatinization (Bennion and Bamford 1997; Felisberto et al. 2015; Luna Pizarro et al. 2013; Wilderjans et al. 2013). For these reasons, the fat reduction in foods may lead to the loss of some important quality attributes, such as texture, mouth-feel, and flavor.

Various studies have been carried out to evaluate the technological functionality of different fat replacers in bakery products (Liu et al. 2016; Liu et al. 2015; Ma and Boye 2015). Inulin has been successfully used as fat replacer in cake batters. Substitutions of fat up to 70% have been achieved without detrimental effects on the cake quality (Rodríguez-García et al. 2012, 2013a, b, 2014). Other polysaccharides such as polydextrose, maltodextrin, amilodextrin, and oligofructose, have been also investigated, but they lead to a decrease in the tenderness of the cakes when their concentrations were higher than 50% (Khalil 1998; Kim et al. 2001; Psimouli and Oreopoulou 2013). Fat mimetics derived from carbohydrates, such as guar and xanthan gums, have allowed the production of fat-reduced

cakes with substitution levels up to 50% (Zambrano et al. 2004). Cereal betaglucans, especially from oat and barley, have been also employed for replacing fat in cakes. Interesting results have been obtained up to 20% of fat substitution (Kalinga and Mishra 2009). However, it is worth mentioning that the incorporation of any functional ingredient into a baked product, will have an impact on its final cost. Consequently, the bakery industry needs to establish cost-effective strategies and processes to achieve the development of functional baked goods at the low-cost as possible, even if they could have the potential to mitigate some diseases, promote health and reduce health care costs.

Ganoderma lucidum is an edible mushroom used long time ago as traditional medicine, pharmaceutical and nutraceutical agent in various Asian countries. It has been employed in the treatment of several human diseases, including hypertension, hypercholesterolemia and various types of cancer, due to its content of several biologically active molecules, especially polysaccharides (Bishop et al. 2015). The major bioactive polysaccharides isolated from the *Ganoderma* species are glucans, β -1-3 and β -1-6 D-glucans (Leskosek-Cukalovic et al. 2010). These compounds might be considered as smart ingredients in functional foods, because of their health-promoting effects and technological functionality, as demonstrated recently in the development of functional yogurts with important angiotensin-converting enzyme-inhibitory activity (Vanegas-Azuero and Gutiérrez 2018).

The aim of this study was to evaluate technological functionality of β GGL (Ganogen®, Progal-BT, Medellín, Colombia), a commercial ingredient obtained by submerged cultivation of *Ganoderma lucidum*, to be used as fat replacers in cakes. The effects of various fat replacement levels (20, 30, 40 and 50%) on the physical properties of cake batters, and on the quality of cakes (determined by their proximate composition, texture, color, water activity, volume, microstructure, and general sensory acceptance) were investigated.

Materials and methods

Materials

The ingredients used in the preparation of cakes are presented in Table 1. Commercial β GGL (Ganogen®) were kindly supplied by Progal-BT, Medellín, Colombia. All reagents and standards used in the analytical determinations were of analytical grade and purchased from Sigma-Aldrich (St. Louis, MO).

Methods

Formulation and preparation of cakes

The cake formulations investigated in this work are shown in Table 1. They were based and balanced according to Bennion and Bamford (1997), taking into account the atmospheric conditions of Bogotá, Colombia (2640 m altitude, and 560 mmHg atmospheric pressure). β GGL were used for replacing vegetable fat at concentrations of 20, 30, 40 and 50%.

For cake preparation, sugar, vegetable fat, emulsifier, potassium sorbate, and salt were creamed in a Hobart N-50 mixer (Hobart Manufacturing Company Ltd., London, UK), by mixing for 10 min at speed 2 (124 rpm). Whole fresh eggs were then added and mixed for 5 min at speed 2. Subsequently, the wheat flour, baking powder, skim milk powder, β GGL and water were added and mixed for 5 min at speed 1 (60 rpm). Finally, the batters were mixed for 1 min at speed 1 (Rodríguez-García et al. 2013a). The temperature of batters was around 25 °C.

The cake batter samples (500 g) were transferred into cake pans, and baked at 175 °C for 45 min using a convection oven (JAVAR, Bogota, Colombia). After baking, the cakes were allowed to cool during 25 min, removed from pans, cooled for 2 h, packaged in polypropylene bags, and stored at room temperature (~ 20 °C) for their evaluation during storage. Each formulation was baked in triplicate.

Specific gravity

The specific gravity of the batter samples was measured using a calibrated density cup of known volume. The cup was filled to the brim with the batter and weighed. The specific gravity was calculated gravimetrically by dividing the weight of known volume of batter by the weight of an equal volume of water (Sowmya et al. 2009).

Flow properties

The flow behavior of the batter samples was determined using a rotational viscometer (Haake viscotester, Thermo Scientific, Waltham, USA) with a sensor SV-DIM. The experiments were performed at 25 °C, in ascending (from 0 to 300 s⁻¹) and descending (from 300 to 0 s⁻¹) runs. The flow curves were adjusted to the Ostwald-de Waele model ($\sigma = K\dot{\gamma}^n$) where K is the consistency index, and n is the flow index. The fit correlation coefficients (R^2) were always higher than 0.99.

Table 1 Cake batters formulations with replacement of vegetable fat by β GGL*

Ingredient	Control	β GGL-20	β GGL-30	β GGL-40	β GGL-50
Wheat flour ¹	200	200	200	200	200
Sugar	150	150	150	150	150
Eggs	80	80	80	80	80
Baking powder ²	2	2	2	2	2
Skim milk powder	20	20	20	20	20
Vegetable fat ³	60	48	42	36	30
β GGL ⁴	0	12	18	24	30
Emulsifier gel ⁵	2	2	2	2	2
Salt	2	2	2	2	2
Water ⁶	150	150	150	150	150

*Amounts in grams

¹8% protein, 0.9% ash, 12.5% moisture²Sodium pyrophosphate, sodium bicarbonate, monocalcium phosphate and corn starch³77% fat, 20.5% moisture⁴93.5% carbohydrates, 4.3% moisture, 2% protein, 0.2% ash⁵Mono and diglycerides of fatty acids (471), propylene glycol (E1520), propylene glycol ester (E477), ethoxylated mono and diglycerides and stearic acid⁶Water + water in reconstituted skim milk

Color

The color of the batters and cakes (crust and crumb) was measured in terms of the L^* , a^* and b^* values of the CIELAB system, using a color spectrophotometer (Color-Quest XE Hunterlab, Minolta Reston USA). The total color difference with respect to control sample (ΔE^*) was calculated according to Eq. (1) (Sanchez-Reinoso and Gutiérrez 2017). Three different measures were carried out for each sample of batters and cakes. The color of the crumb was measured on central slices, on days 1, 7 and 14.

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (1)$$

Light microscopy (LM) and image analysis of air bubbles

The batter samples were observed in an optical microscope (Nikon Eclipse E200, Nikon Co., Ltd., Tokyo, Japan) at 10 $\times$ magnification (objective lens 10 $\times$ /0.25 EPlan Fluor, Nikon). One drop of the batter was placed on a glass slide with a cover slide, carefully positioned to exclude air pockets, assuring a sufficient and constant sample thickness to allow the comparison of the sizes and number densities of the bubbles (Rodríguez-García et al. 2012). The images were captured using the microscope software (Nikon ACT-1, Version 4.3 Nikon), and analyzed by means of the software Optika^{TM} Vision version 4.3 Pro (Ponteranica (BG)—Italy). The measured parameters were the bubbles area (μm^2) and the bubbles size distribution.

Volume of cakes

The volume of cakes was determined by the rise displacement method, according to Sahing and Gulum (2006), with slight modifications (changing rapeseed for rice grains).

Textural properties

The textural properties of the cakes were investigated by conducting a texture profile analysis (TPA). A texture analyzer (TA-TXX Plus Texture Analyzer, Stable Micro Systems, Godalming, UK), provided with the software Texture Exponent 32 (version 4.0.8.0, Stable Microsystems, Godalming, UK) was used. Cylindrical samples (2.0 cm height and 3.5 cm diameter) were compressed twice to 50% of their original height using an aluminum probe (P/75) at a test speed of 5 mm/s, with a 5 s delay between the two compression cycles. A trigger force of 5 g was used. Hardness (g_f), cohesiveness and springiness were calculated from the TPA graphics, as suggested recently by Sahagún et al. (2018). The measurements were performed in triplicate on days 1, 7, and 14. For each sample three different cylindrical portions of the crumb slices were analyzed, at room temperature.

Proximate composition analysis

The protein, ash, moisture and fat contents of the cake samples were determined using the following official methods of analysis: 950.36, 923.03, 935.29, and 922.06,

respectively (AOAC 2012). Total carbohydrates were calculated by difference. The moisture of the cakes was investigated during storage on days 1, 7, and 14.

Water activity

The water activity (a_w) of the cakes was measured during storage (on days 1, 7, and 14), using a CX-2T hydrometer (Decagon, Pullman USA). All measurements were performed in triplicate at room temperature ($\sim 25^\circ\text{C}$).

Crumb microstructure

The crumb microstructure was analyzed by means of scanning electron microscopy (SEM), using a Leo scanning electron microscope Model 200 Fei Quanta (FEI Corporate, Oregon, USA). The cake samples (20×20 mm) were vacuum dried for 12 h at 50°C , and then they were separately placed on the sample holder with the help of a double sided scotch tape, and sputter-coated with gold (80 s, 80mAp). Samples were observed at 15 kV and 1×10^6 Pa vacuum. SEM images of 50X were analyzed using the software ImageJ (Natl. Inst. of Health).

Sensorial acceptance

Hedonic sensory tests were conducted by 60 untrained panelists consisting of staff and students of the Universidad Nacional de Colombia Sede Bogotá. The cake samples were presented in 2.5 cm-cubes, and evaluated for overall acceptance on a 7-point hedonic scale, ranging from extremely dislike to extremely like. Water was provided between evaluations of samples for mouth rinsing. Samples were considered acceptable when the percentage of discrimination as “like” was higher than 60% (Meilgaard et al. 2006). The control cake was presented simultaneously with the fat-replaced sample βGGL -40. Both samples were evaluated in random order among panelists, on the 7th day of storage.

Experimental design and statistical analysis

The experiments were carried out following a randomized block design. The experimental units (500 g batter) were divided into three homogeneous blocks, and then randomly assigned to a treatment group. Analysis of variance by the general linear models (GLM) procedure and mean comparisons by the least significant difference (LSD) test were performed using the statistical analysis system software (SAS, version 9.4, SAS Institute Inc., Cary USA).

Results and discussion

Batter properties

The effects of replacing vegetable fat by βGGL on the properties of the batter samples are presented in Table 2.

Specific gravity

As observed in Table 2, the specific gravity of the batter samples increased from 0.81 to 0.99 g/cc as the fat replacement level increased from 0 to 50%. The specific gravity of the control samples was significantly lower ($p < 0.05$) than that of the fat-reduced samples. No significant differences ($p > 0.05$) were found in the specific gravity of the samples with fat reductions at 20 and 30%, but the specific gravity of the batters containing 50% less fat was significantly higher ($p < 0.05$) than that of the fat-reduced samples at 40%. Taking into account that in cake formulations the fat promotes the incorporation of air into the batter during mixing, the fat substitution by βGGL led to a reduction in the air retention, and consequently the specific gravity increased. Similar results were found by Román et al. (2015) using extruded wheat flour as a fat replacer in cakes, and by Lee et al. (2005), who replaced fat by Oatrim in batter cakes.

Flow properties

Viscosity is a very important parameter of batters, since it is related to the texture and volume of the produced cakes (Bennion and Bamford 1997). For preparation of good quality cakes, the batters should display appropriate viscosity for trapping gas bubbles during mixing, and retaining them during baking (Singh et al. 2016). All the batter samples exhibited a pseudoplastic flow behavior when subjected to shear strain rates between 0 and 300 s^{-1} . The apparent viscosity of the batters decreased as the fat substitution level increased, as indicated by the consistency index (K), which significantly decreased from 43.05 to 16.72 Pa s^n ($p < 0.05$). On the contrary, the flow index (n) significantly increased from 0.47 to 0.62 ($p < 0.05$), as the fat-replacing level increased. This behavior was in agreement with that found by Psimouli and Oreopoulou (2013) who replaced fat in cake batters by different mimetic fat substitutes, such as maltodextrin, inulin, and oligofructose. However, it was different to the flow behavior reported by Kalinga and Mishra (2009), who used betaglucans from oat and barley for replacing fat in cakes. These differences may be explained because the βGGL employed in this study do not retain water, in contrast to

Table 2 Physical properties of cake batters formulated with replacement of vegetable fat by β GGL

Property	Control	β GGL-20	β GGL-30	β GGL-40	β GGL-50
Specific gravity (g/cc)	0.81 ± 0.02^d	0.87 ± 0.01^c	0.89 ± 0.01^c	0.93 ± 0.01^b	0.99 ± 0.02^a
Consistency index K (Pa s ⁿ)	43.05 ± 1.78^a	38.30 ± 3.53^{ab}	32.68 ± 1.39^b	26.37 ± 4.32^c	16.72 ± 0.62^d
Flow index n	0.47 ± 0.01^c	0.47 ± 0.03^c	0.49 ± 0.01^{bc}	0.54 ± 0.05^b	0.62 ± 0.01^a
Thixotropy (Pa/s $\times 10^4$)	2.62 ± 0.11^a	2.43 ± 0.38^{ab}	2.34 ± 0.11^{ab}	2.01 ± 0.31^{bc}	1.77 ± 0.27^c
Color L^*	86.59 ± 0.32^a	85.92 ± 0.18^b	85.33 ± 0.09^c	84.61 ± 0.21^d	83.48 ± 0.01^e
Color a^*	3.07 ± 0.06^d	3.24 ± 0.05^c	3.43 ± 0.04^b	3.47 ± 0.12^{ab}	3.54 ± 0.04^a
Color b^*	18.48 ± 0.14^c	19.03 ± 0.29^{bc}	18.95 ± 0.38^{bc}	19.38 ± 0.26^{ab}	19.67 ± 0.58^a
ΔE^*	0	0.92	1.43	2.22	3.39

Means in the row followed by the same letter are not significantly different by LSD test at the 5% level

the betaglucans from oat and barley, which are recognized by their high water-binding capacity.

Color

The color of the batters significantly changed with the fat reduction, as indicated by the color coordinates L^* , a^* and b^* of the CIELAB system. As observed in Table 2, the lightness (L^*) was significantly reduced (86.59–83.48, $p < 0.05$) as the fat-replacing level increased, indicating that batters became darker as the β GGL concentration increased. On the contrary, the redness (a^*) and yellowness (b^*) values significantly increased ($p < 0.05$) as the fat substitution level increased (3.07 vs. 3.54, and 18.48 vs. 19.67, respectively). However, there were no significant differences ($p > 0.05$) either among the a^* or between the b^* values of the batter samples with fat reductions of 40 and 50%.

The calculated values of the total color difference (ΔE^*) indicated that: (1) there was no perceptible difference for the human eye between the control and the fat-reduced batters at 20% ($\Delta E^* < 1$); (2) minor color differences could be appreciated by the human eye between the control samples and batters containing 30 and 40% less fat ($1 < \Delta E^* < 3$); and (3) the color differences between the control samples and the batters reduced in fat at 50% are obvious for the human eye ($\Delta E^* > 3$) (Martínez-Cervera et al. 2011).

Light microscopy (LM) and image analysis of air bubbles

Representative LM images of the batter samples and their corresponding air bubble area distributions are presented in Fig. 1a–e. As depicted in these figures, as the fat substitution level increased, the number of small air bubbles decreased, and the bubbles size distribution became broader. This behavior may be explained, since fat

stabilizes the air bubbles by forming a film at the air-matrix interface during the creaming process (Rodríguez-García et al. 2012). Consequently, the batter samples with higher fat content displayed a narrower bubble size distribution, and a smaller bubble area. These results are in agreement with the decrease of the consistence index, and with the increase of the specific gravity. A similar behavior has been recently reported in the production of fat-reduced cakes using inulin (Rodríguez-García et al. 2012, 2013a) and extruded wheat flour (Román et al. 2015) as fat replacers.

Quality of cakes

Color

Color is one of the most significant quality attributes in cakes, and it can be attributed to the interaction of the ingredients used in the formulation (Singh et al. 2016). Although color does not necessarily reflects nutritional, flavor and functional values, color determines the acceptability of baked goods (Sahin and Sumnu 2006). The browning of the cakes surface is a result of the Maillard reaction and the caramelization of sugars (Purlis 2010). The effects of fat substitution by β GGL on the color of the cakes' crust and crumb are summarized in Table 3. The values of the color coordinates L^* , a^* and b^* of the crust of the cakes were not significantly affected ($p > 0.05$) by the addition of β GGL. The small differences observed could be due to the slight differences in both the baking time and baking temperature.

The color of the cakes crumb is not affected by the Maillard reaction, but it depends on the ingredients used in the formulation (Bishop et al. 2015). The color of the crumb did not significantly changed ($p > 0.05$) by the fat-replacing, either between treatments or during storage. Similar results were found by Psimouli and Oreopoulou

Fig. 1 Representative LM images and air bubble area distributions of **a** Control, **b** β GGL-20, **c** β GGL-30, **d** β GGL-40, **e** β GGL-50 batters. Magnification: $\times 10$

Table 3 Crust and crumb colors of cakes formulated with replacement of vegetable fat by β GGL

	Control	β GGL-20	β GGL-30	β GGL-40	β GGL-50
Crust					
L^*	38.95 $\pm$ 1.29 ^a	40.29 $\pm$ 1.34 ^a	42.36 $\pm$ 2.75 ^a	43.13 $\pm$ 1.81 ^a	41.89 $\pm$ 4.92 ^a
a^*	18.43 $\pm$ 0.11 ^a	19.63 $\pm$ 1.45 ^a	19.46 $\pm$ 1.08 ^a	18.94 $\pm$ 0.42 ^a	19.03 $\pm$ 0.26 ^a
b^*	33.76 $\pm$ 0.91 ^a	39.90 $\pm$ 8.41 ^a	38.81 $\pm$ 3.94 ^a	38.18 $\pm$ 0.45 ^a	40.38 $\pm$ 0.64 ^a
Crumb					
L^*					
Day 1	78.21 $\pm$ 1.44 ^{aA}	77.09 $\pm$ 1.37 ^{abA}	77.63 $\pm$ 1.38 ^{abA}	77.60 $\pm$ 1.32 ^{abA}	77.16 $\pm$ 1.41 ^{bA}
Day 7	77.87 $\pm$ 1.34 ^{aA}	78.04 $\pm$ 0.5 ^{aA}	78.12 $\pm$ 0.61 ^{aA}	78.08 $\pm$ 0.53 ^{aA}	77.58 $\pm$ 0.66 ^{aA}
Day 14	78.83 $\pm$ 0.87 ^{aA}	78.53 $\pm$ 0.39 ^{aA}	78.65 $\pm$ 0.74 ^{aA}	78.60 $\pm$ 0.66 ^{aA}	78.53 $\pm$ 0.48 ^{aA}
a^*					
Day 1	3.65 $\pm$ 0.53 ^{aA}	3.87 $\pm$ 0.64 ^{aA}	3.61 $\pm$ 0.14 ^{aA}	3.62 $\pm$ 0.41 ^{aA}	3.53 $\pm$ 0.56 ^{aA}
Day 7	3.69 $\pm$ 1.29 ^{aA}	3.27 $\pm$ 0.04 ^{ca}	3.64 $\pm$ 0.16 ^{baA}	3.56 $\pm$ 0.23 ^{abcA}	3.35 $\pm$ 0.16 ^{bcA}
Day 14	3.36 $\pm$ 0.07 ^{aA}	3.42 $\pm$ 0.24 ^{aA}	3.26 $\pm$ 0.31 ^{aA}	3.40 $\pm$ 0.06 ^{aA}	3.29 $\pm$ 0.24 ^{aA}
b^*					
Day 1	24.87 $\pm$ 1.29 ^{aA}	24.91 $\pm$ 0.82 ^{aA}	24.18 $\pm$ 0.58 ^{aA}	23.91 $\pm$ 0.85 ^{aA}	24.15 $\pm$ 1.01 ^{aA}
Day 7	24.80 $\pm$ 1.20 ^{aA}	24.30 $\pm$ 0.51 ^{ab}	24.07 $\pm$ 0.51 ^{aA}	23.94 $\pm$ 0.64 ^{aA}	23.93 $\pm$ 0.77 ^{aA}
Day 14	24.59 $\pm$ 1.20 ^{aA}	24.27 $\pm$ 0.47 ^{ab}	23.93 $\pm$ 0.51 ^{aA}	23.99 $\pm$ 0.90 ^{aA}	23.71 $\pm$ 0.67 ^{aA}

Means in rows followed by the same lowercase letters are not significantly different by LSD test at the 5% level

Means in columns followed by the same uppercase letters are not significantly different by LSD test at the 5% level

(2013) when replacing fat in cakes by maltodextrin, and by Felisberto et al. (2015), who replaced fat in cakes by Chia (*Salvia hispanica L.*) mucilage.

Volume

The volume of cakes is an important parameter determining the preference and acceptance of consumers. Table 4 shows that the volume of cakes tended to decrease as the fat was replaced by β GGL, but the differences were not significant ($p > 0.05$). Similar results were obtained by Román et al. (2015) for fat-reduced cakes using extruded flour paste as fat replacer, and by Singh et al. (2016), who prepared eggless gluten-free rice muffins utilizing black carrot dietary fibre concentrate and xanthan gum. Other authors have indicated that fat-replacing affects the volume of baking products, since less air is incorporated into the batters (Min et al. 2010). The addition of the emulsifier could have played a role in maintaining the volume of cakes, as it has been discussed in other studies (Khalil 1998). Comparable to the results of Psimouli and Oreopoulou (2013), a negative correlation between the volume of cakes and the batters' specific gravity was also found in this study, confirming that our results are well correlated with the differences found in the specific gravity, and flow behavior of the batter samples.

Textural properties

Texture is a very important quality attribute in cakes. It can be used for determining their shelf-life during storage (Wilderjans et al. 2013), as well as for determine their tolerance of manufacturing, packaging, and delivery stresses (Singh et al. 2016). Table 4 presents the results of hardness, springiness, and cohesiveness of the cake samples during storage. On day one, no significant differences ($p > 0.05$) were observed among the hardness values of the cake samples, indicating that in fresh cakes the replacing of fat by β GGL would not have a negative effect on their firmness. The fat-reduced cakes displayed comparable values of springiness and cohesiveness than the control samples ($p > 0.05$) after one day of storage, excepting for the cake samples containing 50% less fat, whose cohesiveness was significantly higher than that of the control samples (0.66 vs. 0.75, respectively, $p < 0.05$). Similar results were obtained by Kalinga and Mishra (2009) and Lee et al. (2004), who replaced fat in cakes by oat and barley betaglucons, and by Nutrim oat bran, respectively.

The hardness of all the cake samples significantly increased ($p < 0.05$) during storage at room temperature, but the fat-reduced samples displayed a higher hardness increase, in comparison to the control cakes. The greater the amount of fat-replacing was, the higher the hardness was. After 14 days of storage, the hardness of the formulations β GGL-20 and β GGL-50 were 120 and 158%

Table 4 Physicochemical properties of cakes formulated with replacement of vegetable fat by β GGL

Textural parameter	Control	β GGL-20	β GGL-30	β GGL-40	β GGL-50
Hardness					
(g _f)					
Day 1	1164.02 $\pm$ 106.82 ^{aB}	1057.34 $\pm$ 45.91 ^{aC}	1125.21 $\pm$ 285.28 ^{aC}	1216.35 $\pm$ 356.26 ^{aC}	1104.36 $\pm$ 268.39 ^{aC}
Day 7	1660.02 $\pm$ 204.92 ^{bA}	1861.55 $\pm$ 48.68 ^{bB}	2028.31 $\pm$ 295.84 ^{abB}	2377.14 $\pm$ 104.06 ^{aB}	2315.37 $\pm$ 335.31 ^{aB}
Day 14	1956.67 $\pm$ 337.65 ^{cA}	2353.44 $\pm$ 136.29 ^{cbA}	2562.55 $\pm$ 114.82 ^{bacA}	2959.70 $\pm$ 518.66 ^{baA}	3098.20 $\pm$ 670.94 ^{aA}
Springiness					
Day 1	0.90 $\pm$ 0.00 ^{aA}	0.92 $\pm$ 0.01 ^{aA}	0.88 $\pm$ 0.07 ^{aA}	0.92 $\pm$ 0.04 ^{aA}	0.89 $\pm$ 0.05 ^{aA}
Day 7	0.83 $\pm$ 0.03 ^{aB}	0.85 $\pm$ 0.00 ^{abA}	0.84 $\pm$ 0.03 ^{aA}	0.85 $\pm$ 0.03 ^{aB}	0.85 $\pm$ 0.02 ^{aA}
Day 14	0.79 $\pm$ 0.01 ^{aC}	0.79 $\pm$ 0.08 ^{aB}	0.83 $\pm$ 0.02 ^{aA}	0.83 $\pm$ 0.02 ^{aB}	0.84 $\pm$ 0.02 ^{aA}
Cohesiveness					
Day 1	0.66 $\pm$ 0.07 ^{bA}	0.73 $\pm$ 0.05 ^{abA}	0.71 $\pm$ 0.04 ^{abA}	0.74 $\pm$ 0.03 ^{abA}	0.75 $\pm$ 0.02 ^{aA}
Day 7	0.45 $\pm$ 0.03 ^{cB}	0.51 $\pm$ 0.00 ^{abB}	0.50 $\pm$ 0.05 ^{bB}	0.53 $\pm$ 0.02 ^{abB}	0.56 $\pm$ 0.02 ^{aB}
Day 14	0.41 $\pm$ 0.04 ^{aB}	0.45 $\pm$ 0.02 ^{aB}	0.43 $\pm$ 0.03 ^{aB}	0.48 $\pm$ 0.03 ^{aB}	0.47 $\pm$ 0.05 ^{aC}
Proximate composition					
Fat (%)	9.44 $\pm$ 0.88 ^a	8.90 $\pm$ 1.98 ^a	6.74 $\pm$ 0.08 ^b	6.12 $\pm$ 0.41 ^{bc}	4.35 $\pm$ 0.12 ^c
Protein (%)	6.53 $\pm$ 0.17 ^a	6.50 $\pm$ 0.21 ^a	6.51 $\pm$ 0.09 ^a	6.52 $\pm$ 0.15 ^a	6.64 $\pm$ 0.16 ^a
Carbohydrates (%)	55.44 $\pm$ 0.69 ^b	55.84 $\pm$ 0.22 ^b	58.56 $\pm$ 1.36 ^a	58.74 $\pm$ 0.78 ^a	60.56 $\pm$ 1.10 ^a
Ash (%)	0.95 $\pm$ 0.02 ^a	0.95 $\pm$ 0.06 ^a	0.96 $\pm$ 0.04 ^a	0.98 $\pm$ 0.04 ^a	0.96 $\pm$ 0.01 ^a
Moisture (%)					
Day 1	27.65 $\pm$ 0.82 ^{aA}	27.81 $\pm$ 1.03 ^{aA}	27.34 $\pm$ 1.47 ^{aA}	27.65 $\pm$ 1.05 ^{aA}	27.49 $\pm$ 1.17 ^{aB}
Day 7	26.86 $\pm$ 1.47 ^{aA}	27.10 $\pm$ 1.33 ^{aAB}	26.64 $\pm$ 0.83 ^{aAB}	26.85 $\pm$ 0.62 ^{aAB}	26.15 $\pm$ 0.65 ^{aAB}
Day 14	26.10 $\pm$ 2.65 ^{aA}	26.26 $\pm$ 0.50 ^{aB}	25.91 $\pm$ 0.28 ^{aB}	26.08 $\pm$ 0.62 ^{aB}	25.72 $\pm$ 0.35 ^{aB}
Water activity (a_w)					
Day 1	0.90 $\pm$ 0.01 ^{aA}	0.89 $\pm$ 0.01 ^{ba}	0.89 $\pm$ 0.01 ^{ba}	0.88 $\pm$ 0.01 ^{ba}	0.89 $\pm$ 0.01 ^{ba}
Day 7	0.89 $\pm$ 0.01 ^{aA}	0.88 $\pm$ 0.01 ^{abA}	0.88 $\pm$ 0.00 ^{bcA}	0.88 $\pm$ 0.00 ^{bcA}	0.87 $\pm$ 0.01 ^{cA}
Day 14	0.89 $\pm$ 0.01 ^{aA}	0.88 $\pm$ 0.00 ^{abA}	0.88 $\pm$ 0.00 ^{bcA}	0.88 $\pm$ 0.01 ^{bcA}	0.88 $\pm$ 0.01 ^{cA}
Cake volume (cc)					
	1086.45 $\pm$ 26.42 ^a	1100.92 $\pm$ 10.96 ^a	1089.18 $\pm$ 19.54 ^a	1053.20 $\pm$ 90.37 ^a	1053.20 $\pm$ 42.50 ^a

Means in rows followed by the same lowercase letters are not significantly different by LSD test at the 5% level

Means in columns followed by the same uppercase letters are not significantly different by LSD test at the 5% level

higher, respectively, than those of the control samples. The fat-replacing by nonfat solids normally leads to a higher hardness values during shelf-life, since fat is an ingredient conferring positive effects on the texture of cakes, by keeping them softer for a long period of time (Bennion and Bamford 1997; Psimouli and Oreopoulou 2013). Moreover, taking into account that the β GGL could be considered as carbohydrate-based fat replacers, they could contribute to the strength of the crumb network through H-bonds among their molecules and the starch molecules of the cakes (Psimouli and Oreopoulou 2013). Thus, the effects of β GGL on the cake hardness could be explained by the different chemical interactions between them and the starch, affecting its retrogradation (Gómez et al. 2007).

As far as the springiness is concerned, it showed a significant decrease ($p < 0.05$) during storage in all the

treatments, but there were no significant differences between the springiness of the control samples and the fat-reduced cakes ($p > 0.05$). These results were well correlated with both the hardness values and the moisture content during the storage period. Moreover, taking into account that the hardness of the cakes increased during the storage, their structure was denser during aging, thus a decreasing in springiness was normal, since it is a measure of the ability of the cakes to recover their structure after compression. A similar behavior was obtained recently by Rodríguez-García et al. (2014) when replacing fat in cakes by inulin.

Cohesiveness quantifies the internal resistance of food structure (Gómez et al. 2007). The cohesiveness of all the cake samples significantly decreased ($p < 0.05$) during storage. However, similar to the springiness, there were no

Fig. 2 Representative scanning electron micrographs and slices of cakes formulated with replacement of vegetable fat by β GGL. **a** Control, **b** β GGL-20, **c** β GGL-30, **d** β GGL-40, **e** β GGL-50

significant differences between the cohesiveness of the control samples and the fat-reduced cakes ($p > 0.05$) after 14 days of storage. Similar results have been reported for other baked goods (Esteller et al. 2004). According to Gómez et al. (2007), these results could be due to the loss of intramolecular attractions between ingredients, drying, and the trend to crumbliness during storage.

Proximate composition

Table 4 presents the proximate composition of the control samples and the fat-reduced cakes, as well as the influence of storage on their moisture content and water activity. As expected, the substitution of fat by β GGL led to a significant decrease in the fat content of the cake samples (9.44 vs. 4.35%, $p < 0.05$). In contrast, the amount of carbohydrates significantly increased ($p < 0.05$), varying from 55.4% in the control samples to 60.6% in the fat-reduced cakes at 50%. The contents of protein and ash did not show significant differences between the samples, being their average values 6.5 and 0.95%, respectively. Similarly, neither the moisture content nor the water activity of the cakes on day 1 changed significantly as a consequence of the fat-replacing, whose average values were of around 27.5% and 0.89, respectively.

Regarding the behavior of the cakes during storage, it can be noticed that the moisture content of the control samples did not significantly change during ageing ($p > 0.05$), while all the fat-replaced cakes, displayed a significant decrease ($p < 0.05$) in the moisture content after 14 days of storage. The higher the fat-replacing was, the more important the decrease in the moisture content was. In spite of this, the values of the water activity of the cakes did not change significantly during storage. These results are in accordance to the high solubility of the β GGL, which do not retain appreciable amounts of water.

Crumb microstructure

The effects of replacing fat by β GGL on the crumb microstructure were analyzed by means of SEM. Representative scanning electron micrographs of the cake samples are presented in Fig. 2a–e. In concordance with the image analysis of the batter bubbles, it can be observed that the control cakes presented smaller and higher density bubble cells (which are seen as caverns in the SEM images) in comparison to the fat-reduced cakes. As the fat substitution level increased, the bubble cells tended to be bigger, while their density was lower, indicating more coalescence of the bubbles during baking (Román et al. 2015). These results are in agreement with the relative viscosity and the specific gravity of the batter samples, taking into account that higher concentrations of fat in the formulations

generates finer crumbs and smaller cells (Cauvain 2003). Moreover, during the baking process, the batters presenting lower viscosities enhanced bubble migration and loss of air cells, before the sponge batter set (Rodríguez-García et al. 2014). From Fig. 2, it is evident that the higher the levels of fat-replacing (i.e. β GGL-40 and β GGL-50) the larger the bubble cells. These results are in agreement with those obtained recently by Rodríguez-García et al. (2012) when replacing fat in sponge cakes by inulin.

Sensorial acceptance

The results of the hedonic sensory analysis of the full-fat cakes and the fat-reduced samples at 40% level are presented in Figure 3 (Electronic Supplementary Material). As depicted in this figure, both cakes presented high values of acceptance. However, the fat-reduced cakes achieved in general higher acceptance than the control samples (97 vs. 95%). Although the control samples presented higher scores in the preference “Like very much” than the fat-reduced cakes (53.3 vs. 38.3%), the former presented lower scores for the preferences “like moderately” and “like slightly” (27 vs. 40% and 15 vs. 18.3%, respectively). Moreover, it is remarkable that there were no negative ratings for the fat-reduced samples, indicating that β GGL could be a good fat substitute in cakes, since they can maintain the sensory characteristics of these baked goods, even at high values of fat-replacing.

Conclusion

Bakery products are important dietary components for people all over the world. Therefore, baked goods with increased nutritional value are of great interest. This study evaluated for the first time the technological functionality of β GGL to be used as fat replacers in cakes. In general, it can be concluded that the replacing of fat by β GGL up to 50% level causes significant changes on the physical properties of batters. Formulations with fat-replacing up to 40% allowed to produce cakes without adverse effects on their physicochemical properties, and with high sensory acceptance. However, the hardness of the fat-reduced cakes was found to increase faster during storage in comparison to the normal cakes. These results suggest that β GGL have good potential to be used as fat replacers in bakery products.

Acknowledgements This research was supported by the Instituto de Ciencia y Tecnología de Alimentos (ICTA) of the Universidad Nacional de Colombia Sede Bogotá. The authors are grateful to Progal-BT for providing the β GGL, and to Jose David Cortés and Jairo Hernando Moreno for their technical assistance in the FT-IR and proximate composition analyses.

References

- AOAC (2012) AOAC international. Official methods of analysis of AOAC international, 19th edn. Gaithersburg, Maryland
- Bennion EB, Bamford GST (1997) The technology of cake making, 6th edn. Springer, Boston
- Bishop KS, Kao CHJ, Xu Y, Glucina MP, Paterson RRM, Ferguson LR (2015) From 2000 years of *Ganoderma lucidum* to recent developments in nutraceuticals. *Phytochemistry* 114:56–65
- Cauvain SP (2003) CAKES I Nature of cakes. In: Caballero B (ed) Encyclopedia of food sciences and nutrition, 2nd edn. Academic Press, Oxford, pp 751–756
- Esteller MS, Amaral RL, Da Silva Lannes SC (2004) Effect of sugar and FAT replacers on the texture of baked goods. *J Texture Stud* 35:383–393
- Felisberto MHF, Wahanik AL, Gomes-Ruffi CR, Clerici MTPS, Chang YK, Steel CJ (2015) Use of chia (*Salvia hispanica* L.) mucilage gel to reduce fat in pound cakes. *LWT Food Sci Technol* 63:1049–1055
- Gómez M, Ronda F, Caballero PA, Blanco CA, Rosell CM (2007) Functionality of different hydrocolloids on the quality and shelf-life of yellow layer cakes. *Food Hydrocoll* 21:167–173
- Kalinga D, Mishra VK (2009) Rheological and physical properties of low fat cakes produced by addition of cereal β -glucan concentrates. *J Food Process Preserv* 33:384–400
- Khalil AH (1998) The influence of carbohydrate-based fat replacers with and without emulsifiers on the quality characteristics of lowfat cake. *Plant Foods Hum Nutr* 52:299–313
- Kim HYL, Yeom HW, Lim HS, Lim S-T (2001) Replacement of shortening in yellow layer cakes by corn dextrins. *Cereal Chem* 78:267–271
- Lee S, Inglett GE, Carriere CJ (2004) Effect of nutrim oat bran and flaxseed on rheological properties of cakes. *Cereal Chem* 81:637–642
- Lee S, Kim S, Inglett GE (2005) Effect of shortening replacement with oatrim on the physical and rheological properties of cakes. *Cereal Chem* 82:120–124
- Leskosek-Cukalovic I, Despotovic S, Lakic N, Niksic M, Nedovic V, Tesevic V (2010) *Ganoderma lucidum*—medical mushroom as a raw material for beer with enhanced functional properties. *Food Res Int* 43:2262–2269
- Liu R, Wang N, Li Q, Zhang M (2015) Comparative studies on physicochemical properties of raw and hydrolyzed oat β -glucan and their application in low-fat meatballs. *Food Hydrocoll* 51:424–431
- Liu K, Tian Y, Stieger M, van der Linden E, van de Velde F (2016) Evidence for ball-bearing mechanism of microparticulated whey protein as fat replacer in liquid and semi-solid multi-component model foods. *Food Hydrocoll* 52:403–414
- Luna Pizarro P, Almeida EL, Sammán NC, Chang YK (2013) Evaluation of whole chia (*Salvia hispanica* L.) flour and hydrogenated vegetable fat in pound cake. *LWT Food Sci Technol* 54:73–79
- Ma Z, Boye JI (2015) Novel health ingredients and their applications in salad dressings and other food emulsions. In: Ma Z, Boye JI (eds) Nutraceutical and functional food processing technology. Wiley, pp 151–187
- Martínez-Cervera S, Salvador A, Muguera B, Moulay L, Fiszman SM (2011) Cocoa fibre and its application as a fat replacer in chocolate muffins. *LWT Food Sci Technol* 44:729–736
- Meilgaard MC, Carr BT, Civille GV (2006) Sensory evaluation techniques, 4th edn. CRC Press, Boca Raton
- Meleady R (2018) Chapter 8—obesity and cardiovascular disease prevention A2—Weaver, Jolanta Urszula. In: Practical guide to obesity medicine. Elsevier, pp 77–88
- Min B, Lee S, Yoo S, Inglett GE, Lee S (2010) Functional characterization of steam jet-cooked buckwheat flour as a fat replacer in cake-baking. *J Sci Food Agric* 90:2208–2213
- Psimouli V, Oreopoulou V (2013) The effect of fat replacers on batter and cake properties. *J Food Sci* 78:C1495–C1502
- Purlis E (2010) Browning development in bakery products—a review. *J Food Eng* 99:239–249
- Rodríguez-García J, Puig A, Salvador A, Hernando I (2012) Optimization of a sponge cake formulation with inulin as fat replacer: structure, physicochemical, and sensory properties. *J Food Sci* 77:C189–C197
- Rodríguez-García J, Puig A, Salvador A, Hernando I (2013a) Functionality of several cake ingredients: a comprehensive approach. *Czech J Food Sci* 31:355–360
- Rodríguez-García J, Salvador A, Hernando I (2013b) Replacing fat and sugar with inulin in cakes: bubble size distribution, physical and sensory properties. *Food Bioprocess Technol* 7:964–974
- Rodríguez-García J, Sahi SS, Hernando I (2014) Functionality of lipase and emulsifiers in low-fat cakes with inulin. *LWT Food Sci Technol* 58:173–182
- Román L, Santos I, Martínez MM, Gómez M (2015) Effect of extruded wheat flour as a fat replacer on batter characteristics and cake quality. *J Food Sci Technol* 52:8188–8195
- Sahagún M, Bravo-Núñez Á, Báscones G, Gómez M (2018) Influence of protein source on the characteristics of gluten-free layer cakes. *LWT* 94:50–56
- Sahin S, Sumnu SG (2006) Physical properties of foods, 1st edn. Springer, Turkey
- Sanchez-Reinoso Z, Gutiérrez L-F (2017) Effects of the emulsion composition on the physical properties and oxidative stability of Sacha Inchi (*Plukenetia volubilis* L.) oil microcapsules produced by spray drying. *Food Bioprocess Technol* 10:1354–1366
- Singh JP, Kaur A, Singh N (2016) Development of eggless gluten-free rice muffins utilizing black carrot dietary fibre concentrate and xanthan gum. *J Food Sci Technol* 53:1269–1278. <https://doi.org/10.1007/s13197-015-2103-x>
- Sowmya M, Jeyarani T, Jyotsna R, Indrani D (2009) Effect of replacement of fat with sesame oil and additives on rheological, microstructural, quality characteristics and fatty acid profile of cakes. *Food Hydrocoll* 23:1827–1836
- Vanegas-Azuero A-M, Gutiérrez L-F (2018) Physicochemical and sensory properties of yogurts containing sacha inchi (*Plukenetia volubilis* L.) seeds and β -glucans from *Ganoderma lucidum*. *J Dairy Sci* 101:1020–1033
- Wilderjans E, Luyts A, Brijs K, Delcour JA (2013) Ingredient functionality in batter type cake making. *Trends Food Sci Technol* 30:6–15
- Zambrano F, Despinoy P, Ormenese RCSC, Faria EV (2004) The use of guar and xanthan gums in the production of ‘light’ low fat cakes. *Int J Food Sci Technol* 39:959–966