Effect of extruded wheat flour as a fat replacer on batter characteristics and cake quality

Laura Román¹ · Isabel Santos¹ · Mario M. Martínez¹ · Manuel Gómez¹

Revised: 26 May 2015 / Accepted: 3 June 2015 / Published online: 13 June 2015
© Association of Food Scientists & Technologists (India) 2015

Abstract The effects of three levels of fat replacement (1/3, 2/3, and 3/3) by extruded flour paste and the effects of the presence of emulsifier on layer cake batter characteristics and final cake quality were studied. Replacement of oil by extruded flour paste modified the batter density and microscopy, reducing the number of air bubbles and increasing their size, while emulsifier incorporation facilitated air entrapment in batter. Emulsifier addition also increased the elastic and viscous moduli of the batter, while oil reduction resulted in a less structured batter. Emulsifier incorporation leads to good quality cakes, minimizing the negative effect of oil reduction, maintaining the volume and reducing the hardness of cakes. Furthermore, consumer acceptability of the reduced fat cakes was improved by the addition of emulsifier. Thus, the results confirmed the positive effect of partial oil substitution (up to 2/3) by extruded flour paste on the quality of reduced fat cakes when emulsifier was incorporated.

Keywords Layer cake · Extruded flour · Emulsifier · Reduced fat · Acceptability

Highlights Extruded flour paste and emulsifier were used as oil replacer in cakes
Oil replacement reduces the number and increases the size of air bubbles in batters
Oil reduction decreases viscoelastic properties, leading to a less structured batter
Emulsifier addition results in good quality cakes minimizing oil reduction effect
Emulsifier incorporation improved consumer acceptability of the reduced fat cakes

✉ Manuel Gómez
pallares@iaf.uva.es

¹ Food Technology Area, College of Agricultural Engineering, University of Valladolid, Avda. Madrid 44, 34004 Palencia, Spain

Introduction

Fat plays an essential role in the processing of shortening cakes, such as layer cakes or pound cakes, and similar products such as muffins and cake doughnuts. In these products fats are responsible for the incorporation of air in the batter in the form of small bubbles. The formation of a structure which incorporates the air in the form of small bubbles will improve the stability of the batter (Wilderjans et al. 2013) while minimizing the coalescence phenomena and the movement of the bubbles to the surface, thus increasing the volume of the cakes and allowing a finer and more uniform grain (Stauffer 1990). Fats also improve the eating quality of cakes as they help to create a more tender texture and extend the shelf life of cakes by slowing the rate of staling through their influence on the retrogradation of starch (Gómez 2008). Nevertheless, an excessive fat intake has been linked to obesity (Bray et al. 2004) and cardiovascular problems, as well as several types of cancer (Rothstein 2006). For this reason, companies and researchers have attempted to minimize the fat and oil content of products like cakes.

Most attempts to reduce the fat content of cakes and muffins have focused on their substitution by several carbohydrate fat replacers such as inulin (Rodríguez-García et al. 2012, 2014a, b; Zahn et al. 2010), β -glucan (Kalinga and Mishra 2009; Lee et al. 2005), cocoa fibre (Martínez-Cervera et al. 2011), modified corn starch (Chung et al. 2010), and potato maltodextrins, polidextrose or crystalline cellulose (Kamel and Rasper 1988; Khalil 1998). The use of protein fat replacers (Conforti 1998; Psimouli and Oreopoulou 2013) and chia gel (Borneo et al. 2010) has also been proposed. Occasionally, emulsifiers or enzymes have also been used, together with fat replacers, in order to improve the quality of these cakes (Conforti 1998; Kamel and Rasper 1988; Rodríguez-García et al. 2014a).

Hydrothermal treatments of flours can gelatinize the starch present in them, depending on their moisture, temperature, and time of treatment. The flours with a high degree of pregelatinization have a greater thickening power in cold water than the traditional flours, and a higher water absorption and retention capacity (Hagenimana et al. 2006; Martínez et al. 2014a), which may help to provide a more tender and less dry texture in cakes with reduced fat. Actually, pregelatinized starches and extruded flours have been successfully proposed to partially replace the oil in oil-in-water emulsions (Lee et al. 2013; Román et al. 2015). Extruded flours have also been used to improve performance in baking, since they allow the quantity of water in the formulation and in the final wheat bread to be increased (Martínez et al. 2013) or the quality of gluten-free breads to be improved (Martínez et al. 2014b).

The aim of this research is to study the effect of pregelatinized extruded flour as an oil replacer (oil substitutions of 1/3, 2/3, and 3/3) and emulsifier addition on the development of reduced fat cakes. The characteristics of the batter in terms of batter density, microscopy, and dynamic rheology were determined. The quality of the cakes was also evaluated with regard to specific volume, weight loss, crumb structure and texture, and they were consumer-tested to determine the acceptability of reduced fat cakes.

Materials and methods

Materials

Wheat flour (10.9 g/100 g moisture; 8.98 g/100 g protein; 81.30 μm mean particle size) was supplied by Harinera Castellana S.A. (Valladolid, Spain). Extruded wheat flour was provided by Molendum Ingredients (Zamora, Spain), which performed the extrusion treatment using a Bühler Basf single screw extruder (Bühler S.A., Uzwil, Switzerland). The extrusion conditions were carried out to ensure starch gelatinization. The length-to diameter (L/D) ratio for the extruder was 20:1. Wheat flour was extruded at a maximum barrel temperature of 160 °C and a feed moisture content of 50 L/h, a feed rate of 500 kg/h, and a screw speed of 340 rpm. The extruded product was dried by convection till it reached 11.2 % moisture. Then, it was ground with a compression roller to a particle size below 200 μm . Sugar, sunflower oil, milk, and liquid pasteurized egg were purchased from the local market. The baking powder was “25×1”, and the emulsifier was “SuperMixo T500”, both supplied by Puratos (Grona, Spain).

Methods

Flour characterization

Flours were analysed following AACC (2010) methods for water hydration capacity (AACC, 56.30-01) and protein (AACC, 46-30.01) which was carried out with a Leco TruSpec[®]N (St. Joseph, MI, USA). The flour particle size was measured using a particle size analyser with laser diffraction (Heros & Rodos, Sympatec, Clausthal-Zellerfeld, Germany) following AACC method 55-40.01.

Cake making

Layer cakes were elaborated using the following formula: 350 g flour, 315 g sugar, 210 g milk, 175 g liquid pasteurized egg, 175 g sunflower oil, and 10.5 g baking powder. A single-bowl mixing procedure was used to prepare the batter. All ingredients were mixed for 10 min (speed 4 for 1 min and speed 6 for 9 min) using a KitchenAid Professional mixer (Kitchen Aid, St. Joseph, Michigan, USA). Cakes were also made by replacing the sunflower oil (1/3, 2/3, and 3/3) with a flour paste of a mixture of extruded flour and water (1:4 flour-water ratio). Furthermore, all cakes were formulated with and without emulsifier (4.5 g) addition. Cake batter (185 g) was placed in disposable oil-coated aluminium pans (109×159×38 mm) and baked at 190 °C for 25 min. After baking, the cakes were removed from the pans and left to cool for 60 min before being placed in sealed plastic bags to prevent drying. Cakes were kept at 20 °C in a chamber until further analysis. Each formulation was prepared in duplicate.

Batter characterization

All the analysis performed for the batter characterization was carried out in duplicate after mixing the batters. Batter density at 20 °C was determined by an Elcometer 1800 pycnometer (Manchester, UK). To visualize bubbles, a drop of batter was placed on a glass slide and overlaid with a cover lip, trying to avoid the inclusion of exogenous air bubbles. The slides were compressed under a 1 kg weight to create a layer of batter of uniform thickness. The batter samples were examined at 40 times magnification using a DM750 microscope (Leica Microsystems, Wetzlar, Germany) equipped with an EC3 video camera, and images were captured using LAS-EZ software (Leica Microsystems, Wetzlar, Germany). Images of each batter were analysed in a 2048×1536 pixel format with Image J software (National Institute of Health, Bethesda, MD, USA). The mean area and number of air bubbles for each area were measured after adjusting the threshold.

The viscoelastic properties of batters were determined using a Haake RheoStress1 rheometer (Thermo Fisher Scientific, Schwerte, Germany) and a Phoenix II P1-C25P unit.

Measurements were conducted at 20 °C using a serrated titanium plate-to-plate system (60 mm diameter) and a gap distance of 1 mm. Batter surface exposed to air between the plates was covered with Pancreac vaseline oil (Panreac Química SA, Castellar del Vallés, Spain) to prevent moisture loss. Before conducting any rheological measurement, the samples were allowed to rest in the measurement position for 5 min as an equilibration time, which is the time necessary to allow the stresses induced during sample mixing and loading to relax. This time was selected following previous time sweeps carried out within the linear region (0.3 Pa) at 1 Hz during 30 min at 20 °C. Then, the linear viscoelastic region was determined by performing a stress sweep (0.01–10 Pa) at a frequency of 1 Hz. Subsequently, a dynamic frequency sweep was executed using the shear stress values within the linear viscoelastic region, over a frequency range between 10 and 0.05 Hz. Analysis was monitored with RheoWin 4 Job Manager software and the rheological parameters were calculated using the Rheowin 4 Data Manager software (Thermo Fisher Scientific, Schwerte, Germany) by performing a regression analysis to adjust the graphs to a power-law model. Thus, in order to characterize the different batters, the storage (G') and loss (G'') moduli at 1 Hz and their dependency against frequency (ω) were calculated by fitting the following equations:

$$G' = G'(1\text{Hz}) \cdot \omega^a$$

$$G'' = G''(1\text{Hz}) \cdot \omega^b$$

where a and b coefficients indicate the frequency dependence of G' and G'' respectively.

Cake quality

Quality determinations were made 24 h after baking. Cake volume was determined with the Volskan Profiler volume analyser (Stable Microsystems, Surrey, UK). The cake-specific volume was calculated as the ratio between the volume of the cake and its weight. Weight loss was calculated as the ratio between weight of batter in the mould and the weight of the cake after baking, expressed as a percentage. Measurements were run in duplicate (two cakes from each batter). Slices of cakes were scanned in an hp Scanjet G3110 (Palo Alto, CA, USA). The scanned images were treated using ImageJ software (National Institute of Health, Bethesda, MD, USA). The image was split in colour channels, the contrast was enhanced and, finally, the image was binarised after applying a threshold. Crumb texture was determined using a TA-XT2 texture analyser (Stable Microsystems, Surrey, UK) with the 'Texture Expert' software. A 25 mm diameter cylindrical aluminium probe was used in a Texture Profile Analysis (TPA) double compression test to penetrate to 50 % depth,

with a test speed of 2 mm/s, and a 30-s delay between the first and second compression. Hardness (N), cohesiveness, and springiness were calculated from the TPA graphic. In order to determine cake staling, hardness was also determined after 7 days of storage in plastic bags at 20 °C, and the difference in hardness ($\Delta\text{Hardness}$) was determined between days 1 and 7. Measurements were made of two central slices (20 mm thickness) from two cakes of each batter.

Consumer testing

Hedonic sensory evaluation of cakes was conducted with 102 cake-usual consumer volunteers from 16 to 65 years of age. Consumer tests were carried out at the Sensory Science Laboratory of the Agricultural Engineering College at the University of Valladolid, Palencia (Spain) in individual booths. Cakes were evaluated on the basis of the acceptability of their appearance, odour, taste, texture, and overall acceptability on a nine-point hedonic scale. The scale of values ranged from *dislike extremely* (score 1) to *like extremely* (score 9). Samples were analysed 1 day after baking. One whole cake and a central slice were presented for appearance evaluation and the rest were divided into 2-cm-wide portions. The samples were presented on white plastic dishes coded with four-digit random numbers and served in random order. Water was available for rinsing. Sensorial evaluation was only made for four cakes: control and 2/3 substitution, both with and without emulsifier.

Statistical analysis

Differences between the cakes were studied by analysis of variance (ANOVA). Fisher's least significant differences (LSD) method was used to describe means with 95 % confidence intervals. The statistical analysis was performed with Statgraphics Centurion XVI software (Statpoint Technologies, Inc., Warrenton, USA).

Results and discussion

Batter characteristics

Table 1 shows the values of the batter characteristics. For the batters without emulsifier, the reduction in the oil content only affected the density, significantly increasing its value 0.05 g/cm³, when the level of substitution was 100 %. This trend could be motivated by the absence of oil in the batter, since oil is placed around the air bubbles maintaining the stability (Stauffer 1990). Moreover, the incorporation of emulsifier reduced the density in all cases, and therefore facilitated air entrapment during batter mixing (Khalil 1998; Kumari et al. 2011). In fact, the microscopy results (Table 1) confirmed that

Table 1 Batter characteristics of control and reduced fat cakes

	Batter density (g/cm ³)	Bubbles mean area (μm ²)	No. of bubbles (no./cm ²)	G' (Pa)	a	G'' (Pa)	b
Control	1.08d	652.05a	61.21bc	133.15bcd	0.380c	101.34bc	0.463bcd
Control+E	1.01c	849.02ab	174.16e	164.85e	0.390c	119.15d	0.484d
RF1/3	1.10de	1294.84b	25.18a	124.85bc	0.385c	90.56b	0.479d
RF1/3+E	0.99bc	852.76ab	107.56d	153.10de	0.384c	107.95 cd	0.484d
RF2/3	1.11de	1325.66b	24.41a	111.20ab	0.337b	73.14a	0.446bc
RF2/3+E	0.98b	774.76ab	116.57d	143.40cde	0.348b	94.09b	0.443b
RF3/3	1.13e	1885.32c	29.34a	100.60a	0.341b	62.78a	0.472 cd
RF3/3+E	0.89a	859.19ab	86.70 cd	196.70f	0.307a	112.30 cd	0.409a

Mean values followed by the same letter in each column are not significantly different at $p \leq 0.05$. RF1/3, RF2/3, and RF3/3= reduced fat cakes with 1/3, 2/3, and 3/3 oil substitution, respectively; E=cakes containing emulsifier. G' and G'' represent storage and loss moduli at 1Hz. a and b coefficients indicate frequency dependence of the storage and loss moduli dependence, respectively

emulsifier addition increased the volume of incorporated air by maintaining the mean size of the bubbles while increasing the number of bubbles. On the other hand, as the level of oil substitution in cakes with no emulsifier was increased, the bubbles were smaller in number but larger in size. Psimouli and Oreopoulou (2013) and Rodríguez-García et al. (2012) also observed a smaller size of bubbles in cakes prepared with shortening and oil, respectively, compared to those with a fat replacer. These authors attributed this effect to the ability of oil to stabilize bubbles by forming a film in the air-matrix interface. Furthermore, Lee et al. (2005), when preparing cakes with lower amounts of shortening replaced by β -glucan amyloextrins, also found that the number of entrapped air bubbles decreased. The emulsifier performs the function of stabilize the bubbles in the case of batters with less oil content, thus improving the structure. It is known that structures with smaller and more uniform bubbles are more stable, and these bubbles tend to remain in the final cake to a greater extent (Stauffer 1990). Consequently, it is expected that the batters with emulsifier will lead to a higher volume in the final cake.

Concerning the viscoelastic properties of the batter, in the frequency range tested the so-called plateau relaxation zone was observed for all the samples. The plateau region is characterized by physical entanglements in the polymeric materials (Ferry 1980). All batters showed a higher elastic modulus than viscous, indicating the solid nature, with both moduli depending on frequency but following a different pattern (Calero et al. 2013) as the different values of a and b coefficients indicated. The trend observed with the a coefficient for both cakes with and without the addition of emulsifier, and in the b coefficient for cakes with emulsifier, is to decrease from 2/3 replacement, indicating a less frequency-dependent modulus. Although the same trend is observed for both coefficients, higher values are exhibited for the b coefficient, which might suggest higher frequency dependence of G'' compared

to G' counterparts. For each of the levels of fat replacement, G' and G'' significantly increased with the addition of emulsifier. Rodríguez-García et al. (2014a) and Sahi and Alava (2003) also found an increase in the moduli of low fat cakes with emulsifier and other fat replacers. Rodríguez-García et al. (2014a) suggested a stronger structure promoted by the water-binding capacity of the emulsifier. Nonetheless, the greater air incorporation and the distribution of this air in the form of fine bubbles generated by the emulsifier may also affect the rheological measurements of the batters. In fact, it has been found that the viscoelastic properties are also dependent on the concentration of air trapped during mixing (Kalinga and Mishra 2009). In this research, G' and G'' moduli were correlated ($p < 0.01$) to the mean area and the number of bubbles; thus, the smaller the area and the higher the number of the bubbles, the higher the elastic and viscous properties of the batters. The decrease in the oil content for the batters without emulsifier resulted in a progressive decrease in the values of G' and G'', indicating a less structured batter, possibly due to the reduced aeration of the batter or to the extra water added with the extruded flour. According to these results, Rodríguez-García et al. (2014a), found a decrease of the moduli when the oil was replaced by inulin and water, which they attributed to a dilution effect. However, Lee et al. (2005) found the opposite results, since the storage modulus was higher for the cakes with decreasing amounts of shortening replaced by β -glucan amyloextrins. The more elastic behaviour of the reduced fat cakes can be attributed to the different fat replacer used and to the fact that they did not add extra water for the replacement.

Cake properties

Volume is an important physical attribute affecting consumer preference and acceptance. Thus, maintaining the volume has

been recognized as one of the challenges of producing baked products with reduced fat (Min et al. 2010). The specific volume of cakes without emulsifier (Table 2) tended to decrease as the oil was replaced by the extruded flour paste. However, the specific volume did not show significant differences from the control sample with up to 2/3 oil substitution. Other authors have also reported that as oil substitution was increased (40–50 %), cakes yielded less volume when using other fat replacers (Borneo et al. 2010; Min et al. 2010; Rodríguez-García et al. 2014a, b). These authors attributed the results to the less air retention during baking, which means that the product is less aerated and denser (Borneo et al. 2010). On the other hand, emulsifier addition minimizes the reduction in volume, since no differences among cakes with emulsifier were found, nor with the control one. Some authors have previously reported an improvement in the volume of the cakes with the addition of emulsifiers (Khalil 1998; Kumari et al. 2011). These results indicate that the cause of the reduction in the specific volume may be due to the stability of the batters, as reported by Rodríguez-García et al. (2014b). This stability is reduced as the oil content is minimized, since oil tends to be around the bubbles, stabilizing them and maintaining more air during baking. At the same time, reducing the viscous and elastic properties ($p < 0.001$) of the batter with the addition of extruded flour paste can also help to increase the loss of stability, as this is directly proportional to the viscosity of the material surrounding the bubbles (Stauffer 1990). However, the inclusion of the emulsifier helps to stabilize the batter due to a better distribution of air bubbles, as shown in the microscopy results. Actually, in the present research greater volume was obtained in the samples with higher batter aeration, since specific volume is inversely correlated to batter density and the mean area of the bubbles ($r = -0.72$; $p < 0.001$). Khalil (1998) and Psimouli and Oreopoulou (2013) also found this negative relationship between cake volume and batter specific gravity in low fat cakes with other carbohydrate replacers.

Concerning weight loss, an increase in weight loss was observed when the emulsifier was added, but this increase was only significant in cakes with the highest substitution. Nonetheless, no clear trend was observed with regards to the oil substitution. Generally, the greater the amount of water content in the formulation, the more water evaporates during baking (de la Hera et al. 2014). Therefore, for reduced fat cakes, in which extra water has been added in the formula, greater baking losses as a consequence of the evaporation of water would be expected. Thus, the reduction in the oil content and its replacement by an extruded flour paste would promote a higher weight loss. Nevertheless, the greater the surface in contact with air in the oven or the higher the specific volume of the bakery product, the higher the water evaporation during baking, leading to a high weight loss (de la Hera et al. 2014). Hence, the decrease in the specific volume for the reduced fat cakes without the addition of emulsifier could counteract the effect of the higher water content. It is also important to consider the high water absorption capacity of the pregelatinized starches. In fact, Hesso et al. (2014) found that the substitution of native flour by a pregelatinized starch increased the water content of cakes. A relationship between a smaller volume and lower weight loss has been found by other authors in studies on cakes/muffins with reduced fat content (Rodríguez-García et al. 2014b; Zahn et al. 2010). However, with the addition of emulsifier, and thus, when minimizing the loss of volume, it is observed that the cakes with more water (higher level of substitution) are those which have greater weight loss.

Figure 1 shows the binarised images of the cell structure of the crumb. As fat content was replaced, the crumb showed a great number and bigger in size continuous air channels (c and d), indicating more coalescence of bubbles during baking. Rodríguez-García et al. (2014a) reported that low G' , G'' and complex viscosity during baking enhanced bubble migration and loss of air cells before the sponge batter set, which is in agreement with the rheological results previously found.

Table 2 Specific volume, weight loss and textural properties of control and reduced fat cakes

	Specific volume (cm ³ /g)	Weight loss (g/100 g)	Hardness (N)	Cohesiveness	Springiness	ΔHardness
Control	2.20bc	9.51a	6.09c	0.637c	0.913d	50.46a
Control+E	2.08b	9.69ab	4.39a	0.625bc	0.879bc	59.55a
RF1/3	2.09b	10.24abc	6.31c	0.600ab	0.918d	42.07a
RF1/3+E	2.18bc	10.96c	4.80ab	0.606abc	0.897 cd	61.41a
RF2/3	1.89a	9.64a	7.29d	0.592a	0.886bc	30.94a
RF2/3+E	2.17bc	10.41abc	5.19b	0.612abc	0.860ab	27.19a
RF3/3	1.77a	10.80bc	8.33e	0.611abc	0.874abc	59.28a
RF3/3+E	2.27c	12.93d	4.19a	0.624abc	0.851a	69.22a

Mean values followed by the same letter in each column are not significantly different at $p \leq 0.05$. RF1/3, RF2/3, and RF3/3= reduced fat cakes with 1/3, 2/3, and 3/3 oil substitution, respectively; E=cakes containing emulsifier

Fig. 1 Binarised images of scanned crumbs with scale bars, 2 cm. **a.** Control, **b.** Control+E, **c.** RF2/3 and **d.** RF2/3+E. RF reduced fat cake with 2/3 oil substitution, E cakes containing emulsifier

Furthermore, the addition of emulsifier leads to cakes with an improved crumb structure of finer and more uniform grain (b and d), in which the large channels were less visible. According to Sahi and Alava (2003) emulsifiers can make the bubbles decrease in size with a more uniform appearance, whereas the less presence of channels indicated that less air escaped during baking.

Table 2 also shows the values of the texture for the cakes studied. The reduction in the oil content increased the hardness of reduced fat cakes with no emulsifier compared to the control, which is related to a drop in the specific volume ($r = -0.67$; $p < 0.001$). In fact, Chung et al. (2010) found that fat reduction in muffins caused an increase in hardness, which was associated with a decrease in both air incorporation and cake-specific volume. With the addition of emulsifier, the hardness was reduced for all the cakes studied. Instead of volume differences, this effect may be due to the fact that the hardness of the cakes was highly sensitive to the air bubble size distribution, as a distribution in small areas resulted in a significantly softer cake (Rodríguez-García et al. 2012), this distribution in small areas was also shown in the structure of the crumb. Thus, the way in which the air is retained into the batter during whipping and baking process would affect crumb hardness. These results are in agreement with those obtained by Khalil (1998) and Kumari et al. (2011). The

cohesiveness of the cakes hardly varies with changes in the oil content or with the addition of emulsifier. Nevertheless, springiness seems to be reduced in cakes with no emulsifier as the oil content is reduced, although no significant differences were observed between the control and 1/3 oil substitution (with the highest value) or with the cakes with higher substitution (2/3 and 3/3). Martínez-Cervera et al. (2011) also observed that the springiness values fell significantly as soluble cocoa fibre increasingly replaced the fat in muffins, reflecting a more compact crumb structure. Zahn et al. (2010) suggested that the increase in elasticity is indicative of the increased strength of the bonds in the three-dimensional crumb network. On the contrary, the incorporation of the emulsifier reduced the elasticity of the control cake, but no significant differences between the cakes with partial or total replacement of oil were observed. Furthermore, the incorporation of the emulsifier also reduced the changes in elasticity as the oil was replaced in the formula. Sahi and Alava (2003) also reported that the addition of emulsifier diminished springiness in sponge cakes since emulsifiers reduce the strength of interactions between the fractions of flour in bakery systems and can lead to a rather crumbly product when applied in excess.

Regarding staling, a greater increase in hardness with the course of time would be expected as the oil was reduced since

fatty acids minimize starch retrogradation (Zhou et al. 2007), reducing staling. However, no significant differences were observed between any of the elaborated cakes. This indicates that extruded flour may also reduce staling, counteracting the effect of the elimination of oil. In fact, Hesso et al. (2014) found that pregelatinized starches used as flour substitutes have a positive effect on retarding the staling of microcakes (degassed baked batters).

Sensorial evaluation

The results of the sensory evaluation of full-fat cakes, with or without emulsifier, and those with a 2/3 of substitution of oil are shown in Table 3. It can be observed that the cake with 2/3 oil substitution and no emulsifier presented a lower valuation in all the parameters compared to the control, which could be related to the volume, texture, and colour differences, as well as other aspects not analysed here such as the juiciness or flavour that provides the oil. Taking into account consumer observations, this cake was considered undercooked, and tasted like uncooked flour. However, the presence of emulsifier, which had no effect on the sensory acceptability of control cakes, significantly improved the appearance and overall acceptability of the cakes with reduced fat content, even reaching the score of the control cake in appearance. These changes can be caused by the effect of emulsifiers on the volume of the cakes. Basically, it is possible to obtain cakes with reduced oil content, with a good consumer acceptability (greater than 5 on a scale of 1 to 9), when substituting this ingredient by an extruded flour. In these cakes, the incorporation of emulsifier helped to increase their evaluation and led to cakes that did not differ from the control in their appearance, and only varied one point in their overall acceptability.

Conclusion

Oil replacement by an extruded flour paste helps to minimize the sensory changes of reduced fat cakes, but modified batter density and microscopy, by reducing the number of bubbles

and increasing their size, and also reducing the viscoelastic properties. These changes produced the decrease in the volume of the final cake and a worse crumb appearance and a harder texture. Nevertheless, the addition of emulsifier minimized these differences. Emulsifier maintained the physical characteristics of the product, such as the batter properties and cake volume, and reduced its hardness while improving the consumer acceptability of the reduced fat cakes compared to the control. Thus, this study has shown that the substitution of oil within the cake formulation by an extruded flour paste up to 2/3 replacement and with the addition of emulsifier can be an effective fat replacer.

Acknowledgments This study was supported financially by Junta de Castilla y León (VA054A12-2), Spain.

References

- AACC (2010) Approved methods of analysis. AACC International, St. Paul
- Borneo R, Aguirre A, Leon AE (2010) Chia (*Salvia hispanica* L.) gel can be used as egg or oil replacer in cake formulations. *J Am Diet Assoc* 110:946–949
- Bray GA, Paeratakul S, Popkin BM (2004) Dietary fat and obesity: a review of animal, clinical and epidemiological studies. *Physiol Behav* 83:549–555
- Calero N, Muñoz J, Cox P, Heuer A, Guerrero A (2013) Influence of chitosan concentration on the stability, microstructure and rheological properties of O/W emulsions formulated with high-oleic sunflower oil and potato protein. *Food Hydrocoll* 30:152–162
- Chung HJ, Lee SE, Han JA, Lim ST (2010) Physical properties of dry-heated octenyl succinylated waxy corn starches and its application in fat-reduced muffin. *J Cereal Sci* 52:496–501
- Conforti FD (1998) Effect of commercial enzymes of the baking and keeping quality of a fat reduced muffin. *J Food Qual* 21:85–94
- de la Hera E, Rosell CM, Gómez M (2014) Effect of water content and flour particle size on gluten-free bread quality and digestibility. *Food Chem* 151:526–531
- Ferry JD (1980) Viscoelastic properties of polymers, 3rd edn. Wiley, New York
- Gómez M (2008) Low-sugar and low-fat sweet goods. In: Sumnu SG, Sahin S (eds) Food engineering aspects of baking sweet goods. CRC Press, Boca Raton, pp 245–273
- Hagenimana A, Ding X, Fang T (2006) Evaluation of rice flour modified by extrusion cooking. *J Cereal Sci* 43:38–46
- Hesso N, Loisel C, Chevallier S, Le-Bail A (2014) Impact of pregelatinized starches on the texture and staling of conventional and degassed pound cake. *Food Bioprocess Technol* 7:2923–2930
- Kalinga D, Mishra VK (2009) Rheological and physical properties of low fat cakes produced by addition of cereal Beta glucan concentrates. *J Food Process Preserv* 33:384–400
- Kamel BS, Rasper VF (1988) Effects of emulsifiers, sorbitol, polydextrose, and crystalline cellulose on the texture of reduced-calorie cakes. *J Texture Stud* 19:307–320
- Khalil AH (1998) The influence of carbohydrate-based fat replacers with and without emulsifiers on the quality characteristics of lowfat cake. *Plant Food Hum Nutr* 52:299–313
- Kumari R, Jeyarani T, Soumya C, Indrani D (2011) Use of vegetable oils, emulsifiers and hydrocolloids on rheological, fatty acid profile and quality characteristics of pound cake. *J Texture Stud* 42:377–386

Table 3 Consumer acceptability of sensorial-tested cakes

	Appearance	Odour	Taste	Texture	Overall acceptability
Control	7.0b	6.9b	7.1b	6.9b	7.2c
Control+E	7.1b	7.0b	7.1b	7.2b	7.3c
RF2/3	5.9a	6.0a	5.7a	5.8a	5.8a
RF2/3+E	7.1b	5.8a	6.0a	6.2a	6.2b

Mean values followed by the same letter in each column are not significantly different at $p \leq 0.05$. RF2/3=reduced fat cakes with 2/3 oil substitution; E=cakes containing emulsifier

- Lee I, Lee S, Lee N, Ko S (2013) Reduced-fat mayonnaise formulated with gelatinized rice starch and xanthan gum. *Cereal Chem* 90:29–34
- 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
- Martínez MM, Calviño A, Rosell CM, Gómez M (2014a) Effect of different extrusion treatments and particle size distribution on the physico-chemical properties of rice flour. *Food Bioprocess Technol* 7:2657–2665
- Martínez MM, Oliete B, Román L, Gómez M (2014b) Influence of the addition of extruded flours on rice bread quality. *J Food Quality* 37: 83–94
- Martínez M, Oliete B, Gómez M (2013) Effect of the addition of extruded wheat flours on dough rheology and bread quality. *J Cereal Sci* 57: 424–429
- Martínez-Cervera S, Salvador A, Muguerza 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
- Min B, Lee S, Yoo S, Inglett G, 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* 78:1495–1502
- 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* 77:189–197
- Rodríguez-García J, Sahi S, Hernando I (2014a) Functionality of lipase and emulsifiers in low-fat cakes with inulin. *LWT-Food Sci Technol* 58:173–182
- Rodríguez-García J, Salvador A, Hernando I (2014b) Replacing fat and sugar with inulin in cakes: bubble size distribution, physical and sensory properties. *Food Bioprocess Technol* 7:964–974
- Román L, Martínez MM, Gómez M (2015) Assessing of the potential of extruded flour paste as fat replacer in O/W emulsion: a rheological and microstructural study. *Food Res Int*. doi:10.1016/j.foodres.2015.04.035
- Rothstein WG (2006) Dietary fat, coronary heart disease, and cancer: a historical review. *Prev Med* 43:356–360
- Sahi S, Alava J (2003) Functionality of emulsifiers in sponge cake production. *J Sci Food Agric* 83:1419–1429
- Stauffer CE (1990) Functional additives for bakery foods. Van Nostrand Reinhold, New York
- Wilderjans E, Luyts A, Brijs K, Delcour JA (2013) Ingredient functionality in batter type cake making. *Trends Food Sci Technol* 30:6–15
- Zahn S, Pepke F, Rohm H (2010) Effect of inulin as a fat replacer on texture and sensory properties of muffins. *Int J Food Sci Technol* 45: 2531–2537
- Zhou Z, Robards K, Helliwell S, Blanchard C (2007) Effect of the addition of fatty acids on rice starch properties. *Food Res Int* 40:209–214