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Cellulose ether emulsions as fat replacers in muffins: Rheological, thermal and textural properties

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ABSTRACT

Sunflower oil, butter and two types of sunflower oil cellulose ether emulsions were used as fat sources in a muffin formulation. The advantage of employing these emulsions is that the final fat content in the muffin formulation is reduced to 49%. The viscoelastic and the calorimetric properties associated with the starch gelatinization of the muffin batter were investigated. In the baked muffins, height, crumb bubble size and instrumental texture were analysed.

The butter batter's viscoelastic properties differed the most from the other batters. Although the butter batter exhibited the highest elastic predominance at room temperature, it was observed to decrease during heating. In the oil and the cellulose emulsion batters, on the other hand, an increase in elasticity was observed during heating. The cellulose emulsions induce a highly significant decrease in the starch gelatinization temperature, in comparison with both the oil and butter batters. The oil muffins are the highest and their texture is the most highly aerated. Both the height and crumb bubble size of the cellulose emulsion muffins were found to lie between those of the oil and the butter muffins. Sensory acceptability of the emulsion muffins was slightly lower, which could be associated with their harder texture.

1. Introduction

Spanish muffins and American muffins are sweet, high-calorie baked products which are highly appreciated by consumers due to their taste and soft texture. The main difference between these types of muffin formulations is the type of fat used: vegetable oil in Spanish muffins and butter in American muffins.

In both types of muffins, the fat is responsible for providing a soft structure, thus avoiding a dry mouthfeel. Fats can help to distribute the gas during the mixing process (Brooker, 1996) and the small fat crystals aid the gas cell stability (Brooker, 1993). Fats improve tenderness, moistness and mouthfeel in baked products. Depending on the type of fat, particular textural properties are obtained. Using oil instead of butter lends greater volume to the final product, since the proteins in the flour are better wrapped in the fat and, thus, it is more difficult to develop the gluten network.

In recent decades, the supply and consumption of sweet bakery products with reduced energy content has increased in response to the demand for products with a lower energy count. The rise in cardiovascular disease and obesity and in other diet-related illnesses has led to consumers taking a greater interest in the ingredients of food products and valuing those with a reduced caloric value more positively. One of the strategies used for this purpose is that of removing the fat (the component that provides the greatest number of calories) and replacing it with other reduced-energy products (fat replacers).

Among the fat substitutes most often used in cakes and muffins, those based on carbohydrates stand out. The substitution of fat for maltodextrins affects the viscosity of the batter and the retention of air in the final cake; thus, total replacement is not recommended and the final volume of the cakes can be improved with certain emulsifiers (Lakshminarayan, Rathinam, & KrishnaRau, 2006) or amilodextrins (Kim, Yeom, Lim, & Lim, 2001). Other studies have focussed on replacing part of the fat with fibres, for example: peach fibre (Grigelmo-Miguel, Carreras-Boladeras, & Martin-Belloso, 2001), inulin (Devereux, Jones, McCormack, & Hunter, 2003), corn bran fibre (Jung, Kim, & Chung, 2005), corn dextrins (Kim et al., 2001), guar gum or carboxymethyl cellulose (Kaur, Singh, & Kaur, 2000), potato pulp and pea flour (Kaack & Pedersen, 2005), β-glucan concentrates prepared from barley and oats (Kalinga &

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Mishra, 2009) or soluble fibre from corn and oats (Warner & Inglett, 1997) or cocoa fibre (Martínez-Cervera, Salvador, Muguerza, Moulay, & Fiszman, 2011).

Another fat substitute that has previously been used in biscuits is an emulsion composed of vegetable oil, water and cellulose ether. This emulsion is semi-solid in consistency and was found to be suitable for reducing the total fat content and can completely replace traditional shortenings in biscuits, while conferring good sensory acceptability (Tarancón, Fiszman, Salvador, & Tárrega, 2013; Tarancón, Sanz, Fiszman, & Tárrega, 2014; Tarancón, Sanz, Salvador, & Tárrega, 2014). The cellulose emulsion could be a good fat replacer in American muffins and an optional means of reducing the fat content (vegetable oil) in Spanish muffins.

The main aim of this work was first to identify the contribution of the type of fat (sunflower oil or butter) to the batter and muffin batter properties, and second, to evaluate two vegetable oil in water cellulose ether emulsions prepared with two different hydroxypropylmethylcelluloses as fat replacers. The rheological and calorimetric properties of the batters and the texture of the final muffins were investigated.

2. Materials and methods

2.1. Emulsion preparation

Oil-water-cellulose ether emulsions were prepared with two different cellulose ethers with thermogelling ability, supplied by The Dow Chemical Co. (K4M and K250M). Both are hydroxipropilmethylcellulose, but K4M has a viscosity of 4 Pas in a 2 g/100 g aqueous solution at 20 °C, and K250M has a viscosity of 250 Pas. The ingredients of the emulsion were sunflower oil with a high level of oleic acid (Carrefour, Madrid, Spain), water and the different cellulose ethers. The proportions used were sunflower oil 51 g/100 g, cellulose ether 2 g/100 g and water 47 g/100 g. The cellulose ether was first dispersed in the oil using a Heidolph stirrer at the lowest speed for 5 min. The cellulose ether was then hydrated by gradually adding the water at 10 °C while continuing to stir. Stirring continued using a homogenizer (Ultraturrax T18, IKA, Germany) until the emulsion was obtained.

2.2. Batter and muffin preparation

Four muffin formulations were prepared (Table 1). A control muffin with vegetable oil (oil formulation), a butter muffin with butter (butter formulation), and two muffins where all of the oil was replaced by a cellulose emulsion (K4M formulation and K250M formulation). The muffins differ in their amount of fat and in their energy content. The butter formulation contains 20% less fat than the oil formulation as butter contains 20% water, and the cellulose emulsion recipe contains 49% less fat. In the butter formulation, the caloric content is 6.2% lower than in the oil formulation, and in the emulsion formulation it is 16.2% lower. The muffin ingredients were wheat flour (Belenguer S.A., Spain. Information provided by the supplier: ≤15 g/100 g moisture, 10 g/100 g proteins), pasteurized liquid egg (Ovocity, Spain), refined sunflower oil (Coosur S.A., Spain) or butter (Président from LB&C-Les Placis, Bourgbarré, France) or cellulose emulsion K4M or K250M, whole milk (Puleva, Spain), sucrose (Azucarera Ebro, Spain), sodium bicarbonate (Martínez, Cheste, Spain), citric acid (Martínez, Cheste, Spain) and salt (sodium chloride).

The batter was prepared in a mixer (Kenwood Major Classic, UK), in which all the ingredients were added. The mixture was beaten for 5 min at speed 4 (320 rpm) until it was smooth.

The batter was poured into a dosing machine (Edhard Corp., Hackettstown, USA), the quantity of batter dispensed was adjusted to 45 g. Twelve paper moulds were arranged in three rows of four muffins on a baking tray and baked for 16 min at 175 °C in an electric oven with top and bottom heat (Fagor Elegance 2H-114B, Guipúzcua, Spain). The muffins were packed in polypropylene bags and stored at 20 °C for one day. At least two formulations were prepared in every case.

Table 1
Muffin formulations.

Ingredients (g/100 g flour)	Oil	Butter	K4M	K250M
Flour	100	100	100	100
Egg	81	81	81	81
Milk	50	50	50	50
Sucrose	100	100	100	100
Oil	46	–	–	–
Butter	–	46	–	–
Emulsion K4M	–	–	46	–
Emulsion K250M	–	–	–	46
Sodium bicarbonate	4	4	4	4
Citric acid	3	3	3	3
Salt	1.5	1.5	1.5	1.5

2.3. Rheological properties

A control stress rheometer, model AR-G2 from TA-Instruments (Crawley, England) with a Peltier heating system, was employed. The batters were maintained at 25 °C for 60 min after preparation as equilibration time before the rheological test. A 40 mm diameter plate–plate sensor geometry with a serrated surface and a 1 mm gap was employed. An equilibration time of 5 min was used in the measurement position.

Temperature sweeps were performed from 25 °C to 95 °C at a heating rate of 1.0 °C/min and a strain amplitude inside the linear viscoelastic response over the whole temperature range (0.0005). The strain amplitude was determined by means of stress sweeps carried out at 25 °C and 95 °C. Vaseline oil was applied to the edges of the samples to prevent the sample drying. The mechanical spectra were recorded from 0.01 to 10 Hz at 25 °C in separate tests. The storage modulus (G'), the loss modulus (G'') and tan(δ) were recorded. Two measurements of each formulation were taken.

2.4. Thermal properties

Modulated calorimetric measurements were taken by a Q2000 calorimeter (TA-Instruments Crawley, UK), equipped with a refrigerated cooling system (RCS 90). The enthalpy and temperature were calibrated using indium (T_{onset} = 155.74 °C and ΔH = 28.69 J/g). The measurements were taken in the batters without adding distilled water (water content from 30.45 g/100 g to 31.21 g/100 g). High volume DSC pans (100 μL) (TA-Instruments) were used. The samples were heated from 25 to 200 °C, then cooled from 200 to 25 °C and heated again from 25 to 200 °C at 2 °C/min. The period of the modulation was 100 s and the amplitude of modulation was 0.5 °C. An empty pan was employed as the reference and dry nitrogen was used as the purge gas at a flow rate of 50 mL/min. The enthalpy was expressed in J/g of sample. The measurements were taken twice for each formulation.

2.5. Specific gravity of batters

The specific gravity (SG) was determined as the ratio of the weighting mean mass of a standard container filled with batter (Wb) compared with that of the same container filled with water (Ww) (Eq. (1)) (specific gravity = 1 g/ml):

$$SG = Wb/Ww \quad (1)$$

Two measurements were taken of each formulation.

2.6. Physical properties of muffins

The muffin height was measured after cooling the muffins for 1 h at room temperature. This measurement was taken from the highest part of the muffin to the bottom part using a calliper. Each formulation was prepared twice, and 7 muffins were measured from each batch.

For bubble measurements, the muffins were cut on a horizontal plane at a distance of 2.5 cm from the base and images of the freshly cut surface of the crumb were captured using a flatbed scanner (HP 4300c, Hewlett Packard, USA). Image processing was performed using Image Pro-Plus 4.5 software (Media Cybernetics, USA). The images were converted to an 8-bit grey scale and segmented separately using a histogram-based segmentation that was defined individually for each image. The bubbles within an area of 0.04 m^2 were counted. Two muffins were measured from each batch (four determinations).

The moisture content of the muffins was determined following AACC Method 44-40 (AACC International, 2000).

The muffins were numbered by marking the underside of the mould and they were weighed before (W3) and after baking and 1-h cooling (W4). The weighting mean mass loss during baking (WLDB) was calculated as follows:

$$\text{Weight loss} = (W3 - W4)*100/W3$$

The instrumental texture measurements were carried out using a TA.XT.plus Texture Analyser (Stable Microsystems, Godalming, UK). Two batches were prepared for each formulation and four muffins were measured from each batch.

The muffins were cut horizontally at the height of the mould, the upper half was discarded and the 2.5 cm high lower halves were removed from the mould.

A double compression test (TPA) was performed using a 75 mm diameter flat-ended cylindrical probe (P/75) and compression to 50% of the initial height, at a speed of 1 mm/s with a 5 s waiting time between the two cycles. From the curves, the parameter hardness (the peak force during the first compression cycle), springiness (the height recovered by the food between the end of the first compression and the start of the second compression), cohesiveness (the ratio of the positive force area during the second compression to the positive force area during the first compression), chewiness (the product of hardness*cohesiveness*springiness), and resilience (area during the withdrawal of the first compression divided by the area of the first compression) were determined.

2.7. Sensory analysis

The sensory analysis was carried out using 80 consumers aged between 20 and 65 years old. The analysis was performed in a sensory laboratory equipped with individual booths (ISO 8589, 1988). Each consumer tasted four muffins (oil, butter, K4M and K250M) presented monadically at a single session following a balanced complete block experimental design. The muffins were coded with random three-digit numbers. The consumers rated the appearance, colour, texture, sweetness, taste and overall acceptance of each muffin sample on a nine-point hedonic scale ranging from “dislike extremely” to “like extremely”. Data acquisition and analysis was performed by Compusense five release 5.0 (Compusense Inc., Guelph, ON, Canada).

2.8. Statistical analysis of the results

A one way-ANOVA was applied to study the effect of the type of fat on each of the instrumental and sensorial parameters. Least significant differences were calculated using the Tukey test at a significance of $P < 0.05$. The SPSS for Windows Version 12 (SPSS Inc., Chicago, USA) was employed.

3. Results and discussion

3.1. Rheology

3.1.1. Frequency sweep at 25 °C

Fig. 1 shows the frequency dependence of the storage modulus (G') and the loss modulus (G'') at 25 °C of the different batters.

In the butter batter, the plateau relaxation zone was observed in the available frequency window. This region is characterized by the fact that the values of G' are higher than G'' over the whole frequency range covered, the frequency dependence being higher for G''.

In the oil batter and the emulsion batters, the crossover between G' and G'' occurred at high frequencies. This crossover point determines the end of the plateau region and the beginning of the transition zone. The reduction in the extension of the plateau region occurred at the lowest frequency in the K250M (4 Hz), followed by the K4M (6 Hz) and finally the oil batter (8 Hz). This behaviour suggests that the reduction in the extension of the plateau region was higher in the K250M emulsion (at the lowest frequency). Studying other protein-polysaccharide systems, other authors obtained similar mechanical spectra with the crossover at higher frequencies. Calero, Muñoz, Cox, Heuer, and Guerrero (2013) found a reduction in the extension of the plateau region by lowering the chitosan content in o/w emulsions. The crossover between G'' and G' at high frequencies was also found in egg yolk dispersions near the isoelectric point (pH 6) when kappa carrageenan was added (Aguilar et al., 2011).

The values of G', G'' and tanδ at 1 Hz of the batters were also found to differ (Table 2). The butter batter shows by far the highest values of G' and G'', followed by the oil batter and both the emulsion batters, which exhibited very similar values of G' and G''. In the butter batter, the values of tanδ were significantly lower, reflecting the greater predominance of the elastic component in this batter.

3.1.2. Viscoelastic properties during heating

For the purposes of investigating the structural changes that take place in the different muffin batters during heating, the viscoelastic properties were studied from 25 °C to 95 °C (the maximum temperature achieved by the heating system). The evolution of the complex modulus $|G^*|$ and tanδ of the different batters is presented in Fig. 2. This time-temperature protocol is not equal to the one applied in the oven (16 min at 175 °C), but was selected so as to provide enough time to distinguish the different structural events, and is considered a valuable tool with which to understand the performance of the different samples during heating.

Three different patterns of behaviour were found, which correspond to the butter batter, the oil batter and the two emulsion batters.

The butter batter was characterized by the highest $|G^*|$ value at the initial temperature (25 °C), as already commented on in the frequency sweep. Different zones were observed in the curve (Fig. 2A): a first zone, from 25 °C to 38 °C, where there was a sharp decrease in $|G^*|$ associated with fat melting. An increase in tanδ is observed over this temperature range (Fig. 2B), denoting a decrease in the batter's viscoelasticity.

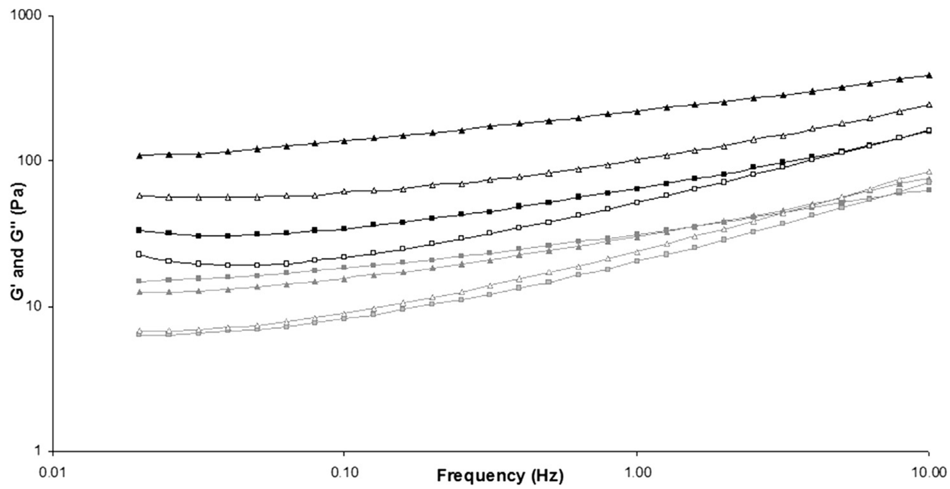

Fig. 1. G′ and G″ as a function of frequency for the different muffin batters at 25 °C (G′: closed symbols and G″: open symbols. Black square: oil, black triangle: butter, grey square: K4M and grey triangle: K250M).

In a second zone, from 38 °C to 52 °C, |G*| continues to decrease but very gently, and tanδ remains almost stable. Over this temperature range, the decrease in |G*| could be associated with CO_2 forming in the batter, which diffused into occluded air cells and expanded, leading to a reduction in batter density (Ngo & Taranto, 1986). Subsequently, from 52 °C until approximately 78 °C, |G*| remains stable. Over this temperature range, tanδ decreases, reflecting a progressive increase in the predominance of elastic behaviour. Finally, at around 78 °C, a gradient appeared and |G*| continued to increase up to the end of the test. This gradient is associated both with the onset of the starch gelatinization process and protein coagulation. In this last zone, tanδ remained almost constant.

The oil batter was mainly defined by the fact that |G*| was stable up to 85 °C, with only a very small decrease in |G*| values observed at 45 °C. At 85 °C, the increase in |G*| associated with the onset of the starch gelatinization process appears. Values of tanδ decreased up to 42 °C, then remained stable up to 50 °C, subsequently continuing to decrease up to around 80 °C. This decrease in the values of tanδ denotes a progressive increase in the viscoelasticity of the system as the temperature rises.

Finally, in the case of the K4M and K250M batters, a slight increase in |G*| is observed up to 60 °C, between 60 and 70 °C the values remain stable and at 70 °C the change in slope associated with the onset of the starch gelatinization process occurs, implying a lower gelatinization temperature than that of the butter and oil batters. The increase in |G*| before 70 °C is associated with the thermal gelation properties of the cellulose ethers (Sanz, Fernández, Salvador, Muñoz & Fiszman, 2005; Sanz, Salvador, & Fiszman, 2004; Sanz, Vélez, Salvador, Muñoz & Fiszman, 2005).

Table 2
Elastic modulus (G′), viscous modulus (G″) and tanδ values at 1 Hz (N = 4) of the different batters.

	G′ (Pa)	G″ (Pa)	tanδ
Oil	60.65a (6.02)	47.93a (5.38)	0.790a (0.010)
Butter	239.55b (25.24)	112.30b (14.42)	0.470b (0.011)
K4M	37.48a (8.64)	22.97a (3.75)	0.620ab (0.042)
K250M	36.01a (8.28)	24.48a (0.93)	0.695ab (0.134)

Values in parentheses are standard deviations. Means in the same column without a common letter differ ($P < 0.05$) according to the Tukey test.

Similarly to the oil batter, tanδ progressively decreased until 75 °C, indicating a more viscoelastic batter.

3.2. Thermal properties of muffin batters (DSC)

The results from the DSC analysis of the batters showed the appearance of an endothermic transition corresponding to starch gelatinization in all the batter samples. The onset temperature (T_{onset}), peak temperature (T_{peak}) and the enthalpy of the transition (ΔH) are shown in Table 3.

It should be recalled that the starch gelatinization temperature is influenced, among other things, by the amount of free water present in the batter. The measurements were taken in the batters without the incorporation of extra water, as the aim was to study the starch gelatinization process with only the water available in the batter system.

As occurs in the rheological results, it may be seen that the gelatinization temperature in the samples containing cellulose is lower. The values of T_{onset} and T_{peak} were significantly lower in both K4M and K250M emulsion batters than in the butter and oil batters. No significant differences were found between K4M and K250M. The fact that the gelatinization temperature in the emulsion batters is lower may be related to the greater amount of water present. It should be considered that the emulsion contains a high water content (47 g/100 g). Although the cellulose ether is a hydrocolloid and has great water retention capacity, the observed results indicate that there is more water available for starch gelatinization in the emulsion batters. Linlaud, Ferrer, Puppo, and Ferrero (2011) studied the effect of adding different hydrocolloids (xanthan gum, locust bean gum, guar gum and high-methoxyl pectin) on the gelatinization properties of wheat dough, adapting the amount of water according to the farinograph absorption value. No significant differences were found between the onset and peak temperatures of samples containing hydrocolloids and the control sample, but significantly lower final gelatinization temperatures were found in the hydrocolloid doughs. These authors also found the greatest water mobility in dough samples containing hydrocolloids. Nevertheless, on the whole, in the case of systems with limit water and the same water content, the addition of hydrocolloids leads to a delay in the starch gelatinization temperature and to increased enthalpy, which is associated with the hydrophilic nature of hydrocolloids (Torres, Moreira, Chenlo, & Morel, 2013). Likewise, the

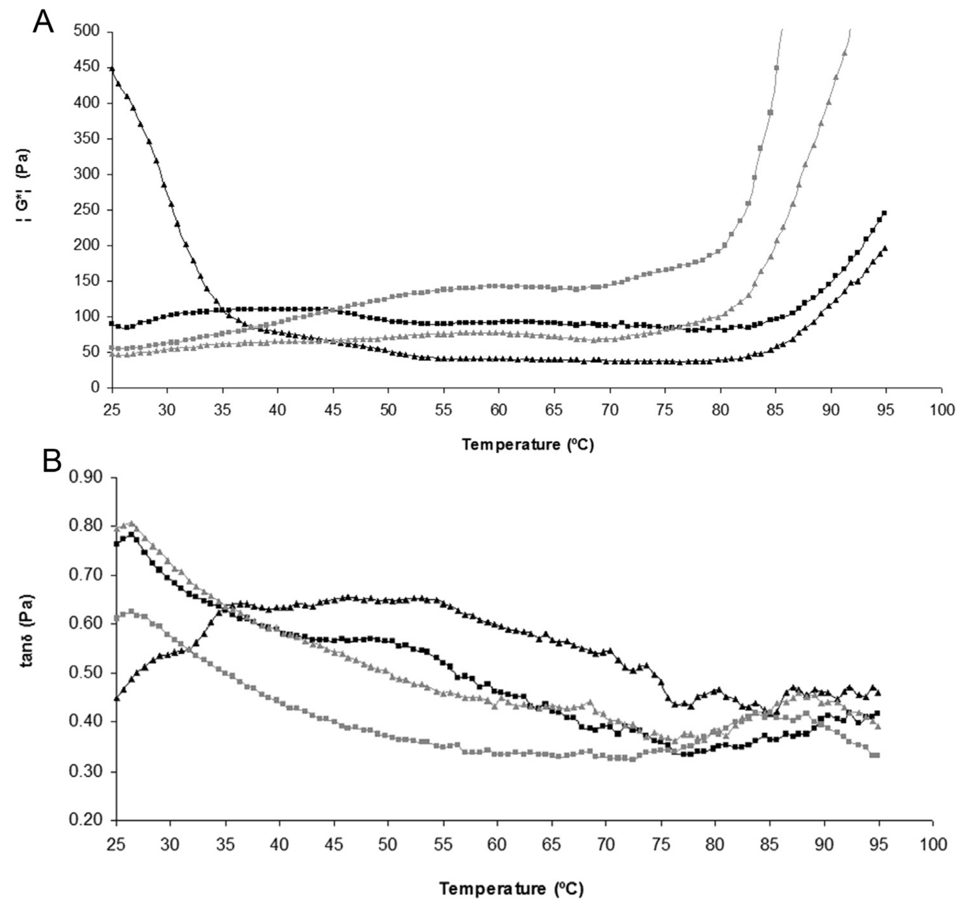

Fig. 2. Effect of increasing temperature on |G*| (A) and tanδ (B) for the different muffin batters. Heating rate: 1.0 °C/min (black square: oil, black triangle: butter, grey square: K4M and grey triangle: K250M).

incorporation of low molecular weight dextrins, such as Nutriose (Martínez-Cervera, de la Hera, Sanz, Gómez, & Salvador, 2013) or Oatrim (Lee, Kim, & Inglett, 2005), to muffin batter leads to a rise in the starch gelatinization temperature, which is associated with a lower degree of water activity.

If the different types of fats are analysed, it may be seen that using butter leads to a slight, but significant, drop in the values of T_{onset} and T_{peak} when compared with the oil batter. This effect may also be associated with the presence of a greater amount of free water in the butter, as around 20 g/100 g of butter is made up of water.

The effect of the batter type on the enthalpy of starch gelatinization was significant (Table 3). This implies that the formulations were found to have significant differences in terms of the energy necessary for the gelatinization of starch. The emulsion batters show significantly higher enthalpy values than the control batter, implying that a greater amount of energy was required for gelatinization. No significant differences were found between the butter and oil batters.

Table 3
Specific gravity and thermal properties (onset temperature (T_{onset}), peak temperature (T_{peak}) and enthalpy (ΔH)) of starch gelatinization process (N = 4) in the different batters.

	SG (g/L)	Thermal properties		
		T_{onset} (°C)	T_{peak} (°C)	ΔH (J/g)
Oil	0.99b (0.01)	87.26a (0.27)	93.47a (0.24)	2.05a (0.09)
Butter	0.84a (0.02)	86.17b (0.38)	92.33b (0.44)	2.09ab (0.12)
K4M	1.00b (0.01)	82.71c (0.21)	89.08c (0.20)	2.25b (0.08)
K250M	0.99b (0.01)	82.78c (0.35)	89.12c (0.48)	2.22b (0.03)

Values in parentheses are standard deviations. Means in the same column without a common letter differ ($P < 0.05$) according to the Tukey test.

3.3. Muffin batter specific gravity

No significant differences (Table 3) were found between the oil and the emulsion batters. However, the butter batter showed significantly lower SG values than all the other batters, indicating that using butter led to greater air incorporation than either the oil or the emulsion batters.

3.4. Properties of the muffins

The height of the muffins is shown in Table 4. The greatest height values were those of the oil muffins. The butter and the K4M emulsion muffins exhibited the lowest significant height, whereas the K250M emulsion muffin was of intermediate height. A significant decrease in height was also found by other authors when the fat was replaced (Lee et al., 2005; Martínez-Cervera et al., 2013).

Moisture and WLDB muffin values are shown in Table 4. The WLDB values were significantly higher in both emulsion muffins and no significant differences were found between the oil and the butter muffins. Despite the higher WLDB in the emulsion muffins, their moisture content after baking was also significantly higher which may be associated with the much greater amount of water present in the initial batter composition. The moisture content of

Table 4
Mean height, moisture, weigh loss during baking (WLDB) and TPA values (H: hardness; S: springiness; Ch: cohesiveness; Cw: chewiness; R: resilience) (N = 8) of the different muffins.

	Height (mm)	Moisture (g/100 g)	WLDB (g)	TPA				
				H (N)	S	Ch	Cw (N)	R
Oil	52.03a (2.21)	19.66a (0.64)	12.85a (0.72)	21.38a (1.94)	0.87b (0.01)	0.60b (0.02)	11.85b (1.03)	0.25b (0.01)
Butter	45.94c (2.32)	21.79b (0.78)	12.76a (0.88)	22.19a (1.26)	0.83a (0.01)	0.55a (0.02)	10.21a (0.72)	0.22a (0.02)
K4M	44.56c (2.15)	24.85c (1.01)	13.98b (1.01)	28.27b (3.37)	0.89c (0.01)	0.64c (0.01)	17.61c (1.09)	0.28c (0.01)
K250M	48.45b (2.32)	24.02c (0.37)	14.56b (0.84)	27.75b (3.44)	0.90c (0.02)	0.63c (0.01)	17.33c (0.72)	0.28c (0.01)

Values in parentheses are standard deviations. Means in the same column without a common letter differ ($P < 0.05$) according to the Tukey test.

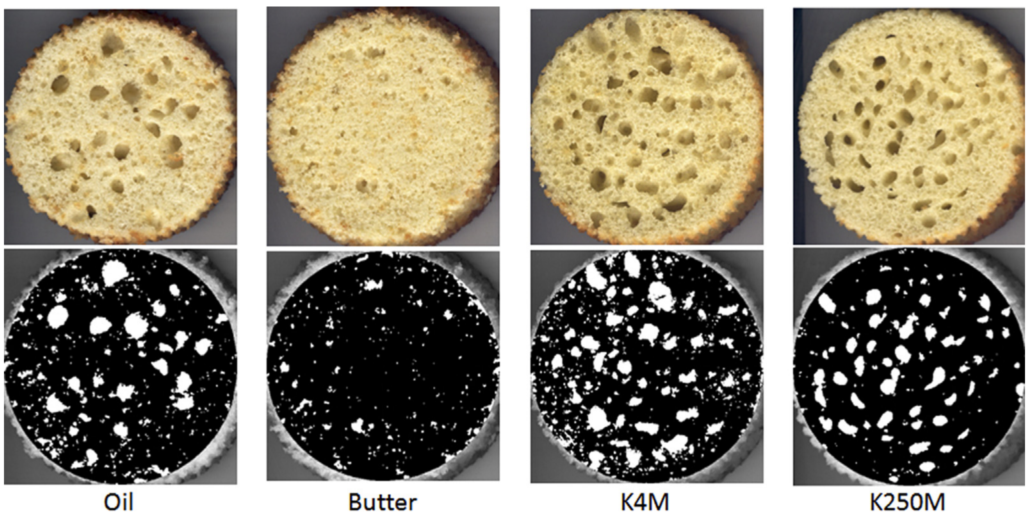

Fig. 3. Crumb images of the different muffins.

the butter muffin was also significantly higher than that of the oil muffin, which is again related to the higher initial moisture content in the butter muffin.

The muffin crumb images are shown in Fig. 3 and the corresponding bubble parameters are shown in Table 5. As expected, the appearance of the oil muffin and the butter muffin was completely different. The oil muffins possess an aerated crumb with bubbles of different sizes, which is the typical structure of a traditional Spanish muffin. On the contrary, the crumb of the butter muffin has a more closed, compact appearance with a smaller total quantity of bubbles and a significantly smaller number of larger and medium-sized bubbles. The appearance of the muffin crumb is coherent with the lower height of the butter muffin, as a consequence of less air expansion. Although the butter batter initially possessed the highest total amount of air (higher SG), this air does not seem to be retained in the muffin structure during the baking process. This fact may be associated with the batter's rheological properties during heating. Initially, at 20 °C, the butter batter possesses the lowest value of tanδ (implying a greater predominance of the elastic component), but elasticity markedly decreases during heating; this is mainly related to the fat melting process, with the post-heating values of tanδ being the highest. This steep decrease in viscoelasticity during heating may reduce the air retention capacity of the batter and, as a consequence, the bubbles will be easily lost, generating a less aerated final texture and a decrease in the final height.

The emulsion muffins were very similar to the oil muffins in appearance, with an aerated crumb made up of bubbles of different sizes. The only difference between the emulsion and oil batters is to be found in the average bubble size, given that the cellulose formations have a significantly higher number of larger bubbles.

The parameters obtained from the Texture Profile Analysis are shown in Table 4. The cellulose emulsion muffins had significantly higher hardness values than either the oil or the butter muffins. No significant differences were observed between the hardness values of the oil muffins and the butter muffins. The cellulose emulsion muffins have the highest values for the parameters of springiness and cohesiveness and there were no differences found between the

Table 5
Bubble distribution (N = 8) of the different muffins.

	Muffins air cells				
	Total air cells	Area distribution ($m^2 \times 10^{-6}$)			Average size ($m^2 \times 10^{-6}$)
		0–0.99	1–9.99	10–100	
Oil	286.8b (61.7)	229.5ab (50.1)	49.6b (12.6)	7.7b (3.5)	1.28b (0.24)
Butter	197.3a (35.1)	168.4a (35.6)	27.4a (6.4)	1.4a (1.7)	0.73a (0.20)
K4M	353.2b (48.4)	285.6b (37.9)	57.3b (10.9)	12.4c (3.5)	1.45bc (0.13)
K250M	278.9b (106.5)	191.4a (105.1)	57.5b (17.6)	9.0bc (4.1)	1.67c (0.51)

Values in parentheses are standard deviations. Means in the same column without a common letter differ ($P < 0.05$) according to the Tukey test.

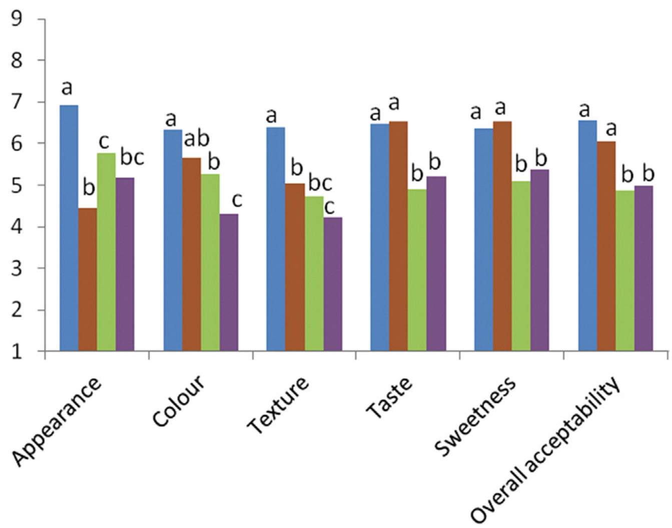

Fig. 4. Sensory acceptability of the different muffins (blue bars: oil, red bars: butter, green bars: K4M and purple bars: K250M). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

K4M and K250M celluloses. The oil muffins have higher values than the butter muffins. By replacing part or all of the fat in muffins or cakes, the hardness and springiness values usually increase (Chung, Lee, Han, & Lim, 2010; Grigelmo-Miguel et al., 2001). Like hardness, springiness and cohesiveness, the samples containing cellulose emulsion had significantly higher chewiness values than either the oil or the butter muffins. Finally, resilience is related to the degree to which the sample recovers when compression ceases. The lowest resilience value was found in the butter muffin, which is coherent with the fact that it was in these muffins that the smallest number of gas cells was found. Although the differences were slight, ranging from 0.22 to 0.28, the cellulose emulsion muffins exhibited the highest resilience values.

The results of the acceptability test are shown in Fig. 4. As can be observed, oil muffins had the highest scores in all the evaluated attributes, with no significant differences found in terms of their colour, taste, sweetness and overall acceptability when compared with butter muffins. Cellulose emulsion muffins presented lower values than oil muffins but, in most of the attributes, these differences are only of one point; so, considering that the cellulose emulsion muffins contain 49% less fat, it is a good result.

4. Conclusions

By taking the rheological changes into consideration, it was possible to discriminate among the samples. The rheological properties of the batter and the final properties of the muffin differed significantly depending on whether oil or butter was used. At room temperature, the greatest predominance of the elastic component is to be found in the butter batter. During heating, however, the viscoelasticity of butter batter is found to decrease significantly between 25 and 38 °C, which is associated with fat melting; over the same temperature range, on the other hand, viscoelasticity increased in the oil batter. These differences in the batter's viscoelastic properties may explain the significantly lower height and the less aerated crumb texture of the butter muffins, as a lower degree of viscoelasticity in the batter during heating is supposed to favour air loss during baking.

Using the cellulose ether emulsion either to reduce total fat or to replace the type of fat induced a very significant decrease in the starch gelatinization temperature in comparison with the oil and butter muffins, which was associated with the higher water content in the emulsion composition. The evolution of the batter's viscoelastic properties during heating was very similar to the oil batter, especially for the cellulose type (K250M) with the highest molecular weight. The appearance of both emulsion muffins was quite similar to the oil muffins, and was characterized by the presence of bubbles of different sizes. The biggest difference between the cellulose emulsion muffins and the oil and butter muffins was found in the parameter of texture, with the emulsion muffins being significantly harder.

The emulsion muffins obtained significantly lower sensory acceptability results, although the differences were only of one point, which is good considering that their fat content is 49% lower than the control muffin.

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