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ORIGINAL PAPER

Sunflower Oil–Water–Cellulose Ether Emulsions as Trans-Fatty Acid-Free Fat Replacers in Biscuits: Texture and Acceptability Study

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Abstract A new vegetable, and trans-fatty acid-free, fat replacer consisting of a sunflower oil–water–cellulose ether emulsion was employed to replace 100 % of the shortening in a short dough biscuit recipe, and the dough and biscuit texture properties were evaluated. In comparison to the shortening dough, the cellulose emulsion dough was significantly ($p<0.05$) softer and more elastic. However, the cellulose emulsion biscuits had higher spreadability, implying that the increase in dough elasticity was not affecting this property, probably because of the decrease in dough hardness. Although the cellulose emulsion biscuits contained 33 % total less fat than the shortening biscuits, their instrumental texture properties were very similar, implying that the cellulose emulsion avoids the increase in hardness associated with fat reduction. This was associated with the thermal gelation ability of the cellulose ethers, which develops during baking. The overall consumer acceptance was significantly ($p<0.05$) higher in the shortening biscuits, but their scores were very similar to those of the cellulose emulsion biscuits (maximum difference 1.1/9 points).

Keywords Shortening replacer · Cellulose ether · Biscuit · Texture · Trans-free

Introduction

High fat consumption, particularly of trans-saturated fatty acids, is associated with the development of various metabolic disorders such as obesity and type 2 diabetes, which, in turn, increase the risk of cardiovascular diseases and some types of cancer (Micha and Mozaffarian 2010).

Biscuits are cereal-based products with high fat and sugar contents and low water content (Chevallier et al. 2000). The functions of fat in this type of product are to improve the texture, appearance, lubricity, mouth feel and flavour, contributing to their palatability (Drewnowski 1992; Grigelmo-Miguel et al. 2001; Zoulias et al. 2002). Fat also adds bulk, retains water, facilitates heat transfer mechanisms at high temperatures (Drewnowski et al. 1998) and increases the feeling of satiety while eating (Leland 1997). Additionally, fats are carriers of liposoluble aromatic molecules, so they act as aroma and flavour precursors and stabilize flavours.

The fats used in biscuit manufacture need to be solid or semi-solid at ambient temperature, which implies a high saturated fatty acid (SFA) content. Preparing biscuit doughs with liquid fats at ambient temperature is not feasible as the dough becomes too smooth and soft, making it difficult to handle (Baltsavias et al. 1999). The most commonly used fats, in biscuit manufacture, are of animal origin, such as butter, or vegetable fats such as hydrogenated vegetable oils. Both of these types of fat contain not only a high percentage of SFAs but also trans-fatty acids.

Reducing the fat content of biscuits and, if possible, improving the quality of the fat employed would provide healthier alternatives. Owing to the important role of fats in this type of product, obtaining low-fat biscuits that are acceptable both technologically (dough handling) and from a sensory point of view (Zoulias et al. 2000; Sabanis and Tzia 2009) is a complex task complicated. In the raw doughs, partially reducing the fat and replacing it with other compounds give rise to considerable changes in their rheological properties, consistency, adhesiveness and ease of

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sheeting and cutting, as well as in their ability to hold their shape during baking. In the baked biscuits, a lower fat content has very negative effects on texture, principally causing greater hardness, which is associated with a loss of lubricating effect and greater development on the gluten network.

The effect of partial replacement of fat by different fat replacers on the quality of biscuits has been studied by different authors. Zoulias et al. (2002) compared the effect of different fat replacers on sugar-free cookie properties. Replacing 35 % of the fat with polydextrose resulted in very hard and brittle products. Further fat replacement, to 50 %, was achieved using maltodextrin, inulin or a blend of microparticulate whey proteins and emulsifiers; however, the final products were hard, brittle and did not expand properly after baking. Replacing part of the fat with inulin gave rise to changes in physical properties, such as increased diameter after baking, higher moisture content and water activity (a_w) and greater biscuit hardness and brittleness. In general, the cookies with maltodextrin were rated as the most acceptable by a sensory panel. Replacing 50 % of the fat with soluble β-glucan and amylodextrins derived from oat flour produced cookies that were not perceived as different from full-fat ones. At higher substitution levels, moistness and overall quality decreased (Inglett et al. 1994). The crispiness of biscuits decreased with increased fat substitution by pectin-based replacers (a blend of gums) or oats. These fat substitutes used produced a significant ($p<0.05$) increase in moisture content. Variations in volume and crumb firmness were associated with the type of fat substitute and the level of fat replaced (Conforti et al. 1996). The use of maltodextrins increased dough consistency, a_w, moisture and hardness (Forker et al. 2011).

Methylcellulose (MC) and hydroxypropyl methylcellulose (HPMC) are hydrocolloids which are obtained by etherifying cellulose and have the ability to gel on heating. The gel formation temperature and the properties of the resulting gel depend on the type and degree of cellulose substitution, the molecular weight, the concentration and the presence of additives (Sarkar 1979). MC and HPMC present good emulsifying properties and can be used to obtain stable emulsions of vegetable oil in water.

The aim of this study was to replace 100 % of the shortening in a biscuit formulation with a fat replacer consisting of cellulose ether–sunflower oil–water emulsion and assess the effects on the dough texture, on the baked biscuit, and on consumer acceptance. This sunflower oil–water–cellulose emulsion is a fat substitute that is free of trans-fatty acids and has a significantly ($p<0.05$) lower level of saturated fatty acids than conventional shortenings. The effect of the degree of methoxyl and hydroxypropyl methyl substitution on the properties studied was also measured.

Materials and Methods

Shortening Replacer Preparation

An oil–water–cellulose ether emulsion (oil in water) was used as shortening replacer. Four different cellulose ethers with thermogelling ability supplied by The Dow Chemical Co. were employed. Their levels of methoxyl and hydroxypropyl substitution are shown in Table 1. The viscosity of the cellulose ethers was 4,000 mPa s (2 % aqueous solution at 20 °C measured by The Dow Chemical Company following reference methods ASTM D1347 and ASTM D2363).

Sunflower oil (Coosol), water and the different cellulose ethers were used to prepare 184 g of emulsion, employing the following proportions: 52.17, 45.65 and 2.17 %, respectively. The cellulose ether was first dispersed in the oil using a Heidolph stirrer at the lowest speed for 1 min. The mixture was then hydrated by gradually adding the water while continuing to stir. The water temperature was 10 °C for all the HPMCs and 8 °C for the MC. Stirring was continued until an emulsion was obtained. The differences in the water temperature employed between HPMCs and MC were attributed to their different hydration temperature according to the specifications given by the manufacturer.

Biscuit Ingredients

The ingredients used to produce the biscuits were (flour weight basis): soft wheat flour 100 % (Belenguer, S.A., Valencia) (composition data provided by the supplier: 11 % protein, 0.6 % ash; alveograph parameters $P/L=0.27$, where P=maximum pressure required and L=extensibility and $W=134$, where W=baking strength of the dough), fat source 32.15 %: shortening (St. Auvent, Diexpa, Valencia) (total fat, 78.4 %; saturated fatty acids, 51 %; monounsaturated fatty acids, 20 %; polyunsaturated fatty acids, 6 %; trans-fatty acids<2 %) or shortening replacer, sugar 29.45 % (Azucarera Ebro, Madrid, Spain), milk powder 1.75 % (Central Lechera Asturiana, Peñasanta, Spain), salt 1.05 %, sodium bicarbonate 0.35 % (A. Martínez, Cheste, Spain),

Table 1 Levels of methoxyl and hydroxypropyl substitution of the different cellulose ethers

Commercial name	Type of cellulose	% methoxyl	% hydroxypropyl
MC A	Methylcellulose	30.0	0.0
HPMC E	Hydroxypropyl methylcellulose	29.1	9.1
HPMC F	Hydroxypropyl methylcellulose	29.0	6.8
HPMC K	Hydroxypropyl methylcellulose	22.5	7.7

ammonium hydrogen carbonate 0.2 % (Panreac Quimica, Barcelona, Spain) and tap water 9 %. In the formulations with a shortening replacer, glycerol (3.2 %) (Panreac Quimica, Barcelona, Spain) was also added to control the a_w.

Biscuit Preparation

The shortening or shortening replacer, sugar, milk powder, leaving agents, salt, water and glycerol (in the case of biscuits made with the shortening replacer) were mixed in a mixer (Kenwood Ltd., U.K) for 1 min at low speed (60 rpm), the bowl was scraped down and they were mixed again for 3 min at higher speed (255 rpm). The flour was added and mixed in for 20 s at 60 rpm then mixed for a further 40 s at 60 rpm after scraping down the bowl once more. The dough was sheeted with a sheeting machine (Parber, Vizcaya, España) and moulded to 64 mm in diameter×3.4 mm in thickness. Twenty biscuits were placed on a perforated tray and baked in a conventional oven (De Dietrich, France) for 6 min at 200 °C. The trays were then turned 180 °C, bringing the side that had been at the back to the front of the oven to ensure homogenous baking, and baked for a further 6 min at the same temperature. The oven and the oven trays were always the same, the trays were placed at the same level in the oven and the number of biscuits baked was always the same. After cooling, the biscuits were packed and stored in heat-sealed metalized polypropylene bags. The biscuit samples were evaluated on the following day in all cases.

Dough Texture Measurements

Different texture tests were conducted to ascertain the properties of the dough. The sheeted dough (10 mm in thickness) from the different formulations was analysed. A TA-XT.plus texture analyzer equipped with the Texture Exponent software (version 2.0.7.0. Stable Microsystems, Godalming, UK) was used. Three different types of tests were performed: wire cutting, sphere penetration and double compression. The test speed was always 1 mm $s^{-}1$ and the trigger force was $5g$ in the wire cutting and sphere penetration tests and $10g$ in the double compression test. Each test was conducted on six replicates of each formulation.

Wire Cutting Measurements

Discs of dough of 10 mm in thickness and diameter of 64 mm were sheared transversally through the middle with a wire cutter. The area under the force/displacement curve was calculated and considered an index of dough hardness.

Double Compression Test (Texture Profile Analysis)

Dough discs of 10 mm in thickness with a diameter of 50 mm were compressed to 30 % of their initial height using a 75-mm-diameter aluminium plate (P/75) with 5 s of waiting time between the two cycles. The parameters obtained from the curves were hardness (the peak force during the first compression cycle), springiness (the height that the food recovered between the end of the first compression and the start of the second compression) and cohesiveness (the ratio of the positive force area during the second compression to the positive force area during the first compression).

Biscuit Evaluation

Dimensions

The biscuit diameter was measured by arranging ten biscuits along the length ruler and recording the average diameter. The biscuit thickness was measured by stacking ten biscuits. The measurements were expressed in cm as the mean value/ten of four different trials.

Moisture Content and Water Activity (a_w)

The moisture content of the biscuits was determined in three replicates of each formulation according to a modification of Approved Method 44-15A (AACC International, 2009). A total of 5 g of samples was put in an oven at 105 °C until they reached a constant weight.

Water activity (a_w) was determined in three replicates of each formulation using a Decagon AquaLab meter (Pullman, WA, USA) calibrated with a saturated potassium acetate solution (a_w=0.22).

Texture Analysis

The texture of the biscuits was measured using the same texture analyzer as described before. A test speed of 1 mm $s^{-}1$ was used for all tests. Ten replicates of each formulation were conducted. Two different tests were performed: a three-point break test and a bite test.

Three-Point Break Test The biscuits were broken with the three-point bending rig probe (A/3 PB). The experimental conditions were: supports 50 mm apart, a 5-mm probe travel distance and a trigger force of $20g$. The force at break (N) (breaking strength) was measured.

Bite Test The penetration tests were conducted with the upper Volodkevich Bite Jaw, penetrating the sample (half biscuit) to 2 mm; a trigger force of $20g$ was set. The maximum force at penetration (N) was measured.

Consumer Sensory Analysis

A total of 100 untrained panellists (consumers) aged from 15 to 64 years, who frequently consumed this type of biscuit, took part in the study. Each consumer received five biscuits (the control and one for each shortening replacer) presented individually in a single session following a balanced complete block experimental design. The biscuits were coded with random three-digit numbers. Consumer acceptance testing was carried out using a categoric nine-point hedonic scale (9=like extremely and 1=dislike extremely). The consumers had to score first their liking for the 'appearance' and 'colour', and after eating the sample their liking for 'texture', 'flavour', 'sweetness' and 'overall liking' for each biscuit sample.

Statistical Analysis

Analysis of variance (one way) was applied to study the differences between formulations; least significant ($p<0.05$) differences were calculated by Tukey test and the significance at $p<0.05$ was determined. These analyses were performed using SPSS for Windows Version 12 (SPSS Inc., USA).

Results and Discussion

Dough Characteristics

Rheological (texture) properties are a consequence of the dough's internal structure and determine the processability and quality of the biscuits (Piteira et al. 2006). The consistency, elasticity and cohesiveness of the dough should be appropriate to guarantee adequate processing and final texture. The dough structure and properties are determined by the composition and proportion of the ingredients; fat is a crucial structural component. Different texture tests were carried out to evaluate the effect of shortening replacement by the different oil–water–cellulose emulsions on the dough texture.

Wire Cutting Test

This test consists in pushing a wire through the sample from an initial indentation to a steady-state cutting stage. The wire cutter has the advantage of presenting a constant contact area with the sample, minimizing the friction effects (Dunn et al. 2007). The test was conducted to measure the resistance of the dough when sliced through by a wire cutter. The relation between force and displacement in a wire cutting test depends on a combination of fracture, plastic/viscous deformation and surface friction effects (Laguna et al. 2011).

The force/displacement curves for the different doughs are shown in Fig. 1. This curve shown has two different parts: a first part in which the force increased over time, corresponding to the initial indentation of the sample by the wire, and a second part in which the cut reached a steady state and the curve formed a plateau (Goh et al. 2005).

As can be observed, the shortening dough (control) presented higher force values than those prepared with the oil–water–cellulose emulsions.

The slope of the initial portion of the rise in the curve indicates the rigidity of the samples whereas the area behind the curve can be associated with the shearing work and thus can be related to biscuit hardness. The slope of the first part of the control dough curve was also steeper, indicating that greater force was required for the initial cut in this dough. The area under the curve (AUC) values from the cutting tests on the different doughs are shown in Table 2. As with the curve profiles, the control dough prepared with shortening presented a significantly ($p<0.05$) higher AUC than the doughs with cellulose, indicating that greater force was needed to cut it. No significant ($p>0.05$) differences were found between the doughs prepared with the different cellulose ethers. Consequently, replacing the shortening with the oil–water–cellulose emulsions produced doughs with less resistance to cutting, reducing the work needed to cut the samples.

Double Compression Test (Texture Profile Analysis)

The curves obtained in the double compression test are shown in Fig. 2. As in the previous tests, the doughs prepared with the different cellulose ether emulsions presented a group of similarly shaped curves while that of the dough with shortening was different from the rest. Equally, the shortening dough was again found to be harder than those prepared with the cellulose ether emulsions and no significant ($p>0.05$) differences were found between these (Table 2). The lower dough hardness observed in all the texture tests when the shortening was replaced by the cellulose emulsions contrasts with the results of previous studies in which greater hardness was found when the fat content was reduced, whether or not a replacer was employed. The increased hardness described in the literature when biscuits were made with lower fat contents is associated with the ability of fat to lubricate, weaken or soften the structure of food components. Also, reducing the fat content of the dough implies that more water is necessary to yield a suitable consistency for dough piece forming. This extra water allows more flour protein hydration and more gluten formation, which results in a tougher dough. For example, Sudha et al. (2007) found an increase in dough hardness as the fat level decreased in soft dough biscuits. Employing maltodextrin and polydextrose as fat replacers reduced the dough

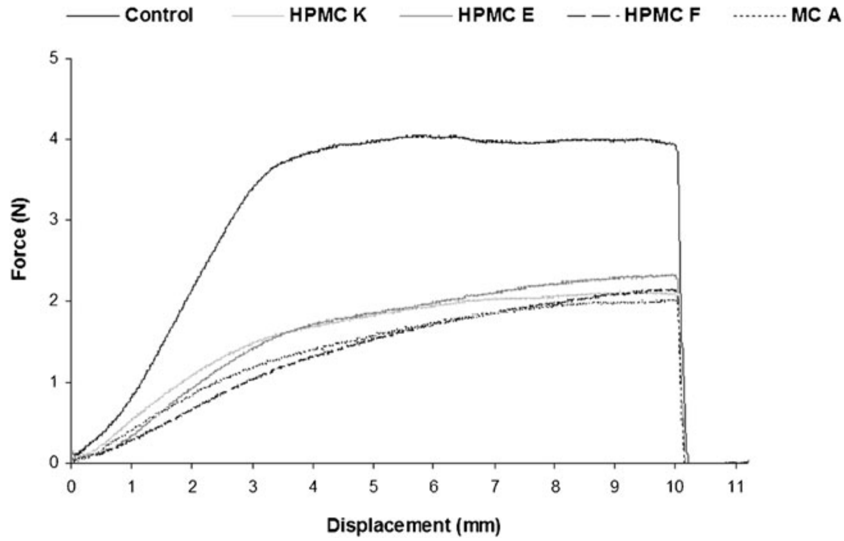

Fig. 1 Wire cutting representative curve profiles of the control and fat-replaced biscuit doughs

consistency and dough hardness to some extent and further improvement in dough characteristics was possible with the addition of glycerol monostearate and guar gum.

The reason why the doughs prepared with the trans-fatty acid-free cellulose emulsions were less hard despite the significant reduction (33.13 %) in the total fat content may be linked to the fact that the source of fat in the emulsion is a liquid vegetable oil as the lubrication effect of fat has been associated with the liquid oil fraction in the shortening. The doughs prepared with the cellulose emulsions contained 33.13 % less total fats but 100 % of their fat was liquid oil. By coating the sugar and flour particles, the oil reduces the mixing time, reduces the energy required for mixing and smoothens the dough (Pareyt and Delcour 2008). Also, the high water absorption rate of the cellulose ethers in the emulsion means that the greater part of the water in the formulation would not be totally available for hydrating the proteins, reducing the increased consistency associated with a more developed gluten network.

The texture profile analysis showed that the springiness and cohesiveness of all the doughs prepared with the cellulose ether emulsions (Table 2) were greater than in the shortening formulation and that the degree of methoxyl and hydroxypropyl substitution in the cellulose ethers did not significantly ($p>0.05$) affect the dough springiness.

Unlike the hardness results, the tendency for springiness and cohesiveness to rise when the fat content is reduced was expected from the functionality generally described for fats in biscuit doughs. However, the explanation for this effect cannot be associated with the same causes or at least not if it is considered that the water did not bring about greater gluten network hydration in the cellulose emulsions because its priority use was to hydrate the cellulose ether. In general, the greater springiness of the dough when the fat content was reduced was associated with the fact that, in the absence of shortening, the water or sugar solution would interact with the flour protein to create cohesive and extensible gluten, which confers elasticity and cohesiveness. Hadnadev et al. (2011) stated that blends consisting of vegetable fat and different type, content and concentration of an aqueous maltodextrin gel had lower hardness than those with vegetable shortening. In the case of the doughs with cellulose emulsions, the most likely cause of the increased springiness and cohesiveness has to be associated with the presence of the cellulose emulsions themselves rather than with their effect on the functionality of the other ingredients. Sudha et al. (2007) obtained higher elasticity, cohesiveness and adhesiveness values on reducing the fat content. From a technological point of view, an increase in the elasticity of biscuit dough is not an advisable property (Sudha et al.

Table 2 Dough texture characteristics for the control and the different cellulose emulsion formulas

Dough sample	Wire cutting	TPA		
	AUC (N mm)	Hardness (N)	Springiness	Cohesiveness
Control	37.95 a (5.79)	128.9 b (25.8)	0.36 a (0.03)	0.24 a (0.01)
HPMC K	15.78 b (0.93)	42.6 a (8.8)	0.53 b (0.10)	0.38 b, c (0.06)
HPMC E	15.29 b (1.66)	30.6 a (6.2)	0.67 b (0.13)	0.44 c (0.05)
HPMC F	13.40 b (0.63)	31.6 a (7.0)	0.51 a, b (0.22)	0.35 b (0.09)
MC A	13.26 b (1.21)	36.6 a (3.3)	0.58 b (0.15)	0.35 b (0.05)

Values in parentheses are standard deviations. Means in the same column with the same letter do not differ significantly ($p<0.05$) according to Tukey's test

AUC area under force/time curve

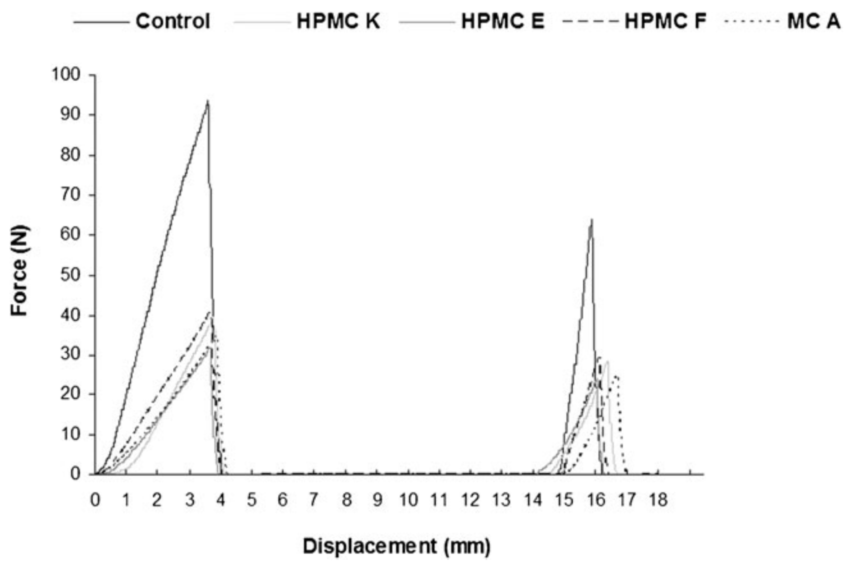

Fig. 2 Double compression representative curve profiles of the control and fat-replaced biscuit doughs

2007) as, if the dough is too elastic, it will tend to recover its initial shape after sheeting, reducing the spread and affecting the final dimension of the biscuit.

In short, total replacement of the shortening by the cellulose emulsions prepared in this study altered the rheological properties of the doughs significantly ($p<0.05$), causing them to become softer, more elastic and more cohesive. The type of cellulose ether substitution did not exert a significant ($p>0.05$) effect.

Biscuit Evaluation

Dimensions

One decisive aspect of final biscuit quality is the expansion of the dough during baking as this determines the size and texture of the biscuit (Seker et al. 2010). The diameter and thickness of the biscuits are shown in Table 3. Both the diameter and the thickness were significantly ($p<0.05$) greater in the biscuits formulated with the cellulose ether emulsions than in those formulated with shortening, without any significant ($p>0.05$) differences between the different types of cellulose ether.

Fat content is a decisive factor for the final dimensions of the biscuit. The fat covers the proteins and starch granules, isolating them and interrupting the continuity of the structure formed by the protein and starch (Pareyt et al. 2008). In the presence of fat the dough is less elastic, which is an advantage in biscuit-making because it prevents the dough from shrinking after sheeting. As a result, reducing the fat content of biscuit formulations generally leads to lower biscuit spread, which has a negative effect on the final biscuit quality (Sudha et al. 2007). For instance, biscuits in which up to 50 % of the fat was replaced by maltodextrin, inulin or a blend of microparticulate whey proteins and emulsifiers did not expand properly after baking (Zoulias et al. 2002). The results of replacing the shortening with the cellulose ether emulsions showed that the tendency in the cellulose emulsion doughs differs from that which is found when fat is eliminated or is replaced by other substitutes as the biscuits formulated with the cellulose ether fat replacer showed greater expansion during baking (greater final diameter and thickness).

Here again, the greater diameter of the biscuits made with cellulose ethers cannot be explained in terms of dough elasticity as these doughs presented greater elasticity than

Table 3 Physical and texture characteristics of biscuits for the control and the different cellulose emulsion formulas

Biscuit sample	Length (cm)	Thickness (cm)	Moisture % (*w*/*w*)	a_w	Three-point break test max. force (N)	Penetration test max. force (N)
Control	6.47 a (0.07)	0.63 a (0.03)	0.632 a (0.221)	0.305 a (0.005)	16.73 a (2.48)	46.16 a, b (10.16)
HPMC K	6.79 b (0.04)	0.74 c (0.05)	2.218 c (0.565)	0.317 a (0.005)	16.56 a (2.44)	39.10 a (4.33)
HPMC E	6.71 b (0.03)	0.70 b, c (0.01)	2.090 b, c (0.337)	0.282 a (0.005)	15.63 a (1.77)	48.54 b (7.68)
HPMC F	6.72 b (0.05)	0.72 b, c (0.03)	1.640 b (0.187)	0.264 a (0.005)	23.51 b (3.47)	48.786 b (12.89)
MC A	6.73 b (0.04)	0.67 a, b (0.04)	2.163 b, c (0.164)	0.268 a (0.005)	15.39 a (2,16)	38.97 a (7.22)

Values in parentheses are standard deviations. Means in the same column with the same letter do not differ significantly ($p<0.05$) according to the Tukey's test the control dough. In this case, the greater expansion of the biscuits made with cellulose ethers may be explained by the lower hardness of these doughs, which would therefore be more fluid, giving the dough greater diameter during sheeting and baking.

Moisture Content and Water Activity (a_w)

As expected, the biscuits prepared with the cellulose emulsions presented a significantly ($p<0.05$) higher moisture content than those with shortening (Table 3) owing to the higher percentage of water in the formulation of the former. A comparison among the different types of cellulose ether showed up a slightly significant ($p<0.05$) difference between the HPMC F and HPMC K biscuits, being greater for HPMC K than for HPMC F.

However, despite the differences in moisture, the a_w values of the different biscuits did not differ significantly ($p>0.05$). This was because glycerol was added to the cellulose emulsion formulations to reduce the water activity. The a_w values fluctuated between 0.2 and 0.3, in other words, below the permitted limit after which microorganism growth takes place and enzymatic oxidation reactions appear (Labuza and Dugan 1971).

Biscuit Texture Analysis

The mechanical properties of the biscuits have a direct effect on sensory perception and are related, therefore, to consumer acceptance of these products (Baltsavias et al. 1999). One of the main quality defects in biscuits that have a lower percentage of total fat, with or without the use of replacers, is increased fracture force, which implies increased hardness, distancing these biscuits from the typical hardness level of short dough biscuits (Baltsavias et al. 1999; Forker et al. 2011).

The three-point break test measures the force required to break a biscuit in half. The force/displacement curve profiles obtained in this test are presented in Fig. 3. The texture profiles of all the biscuits were very similar. Comparison between the different types of cellulose ether showed that the biscuits containing the HPMC with the lowest percentage hydroxypropyl groups (HPMC F) registered the greatest break force compared to the other samples (Table 3), so this formulation was the hardest. The greater hardness in samples with HPMC F may be explained by the lower moisture content in this sample (Table 3). The control biscuits did not exhibit significant ($p>0.05$) differences in maximum break force values from those of the biscuits containing MC and HPMC types K and E. Nor were significant ($p>0.05$) differences found between biscuits with a zero hydroxypropyl group content (MC A) and those with the highest hydroxypropyl substitution (HPMC K and E), so this substitution appears not to affect the break properties of the biscuits studied.

The similarity between the texture curves of the biscuits with shortening and those with the cellulose emulsions is worth noting as one of the main quality defects associated with fat reduction/replacement in biscuits is a considerable change in texture, mainly in the form of a very significant ($p<0.05$) increase in hardness.

The fat surrounds the proteins and the starch granules, isolating them and breaking the continuity of the protein and starch structure. This phenomenon results in eating properties after baking that are described as less hard, shorter and more inclined to melt in the mouth. Where the sugar level is high, the fat combines in the oven with the syrupy solution, preventing it from setting to a hard vitreous mass on cooling (Manley 2000). Also, the decrease in the fat content of the dough needs to be compensated with more water to yield consistencies suitable for dough piece forming, and this extra

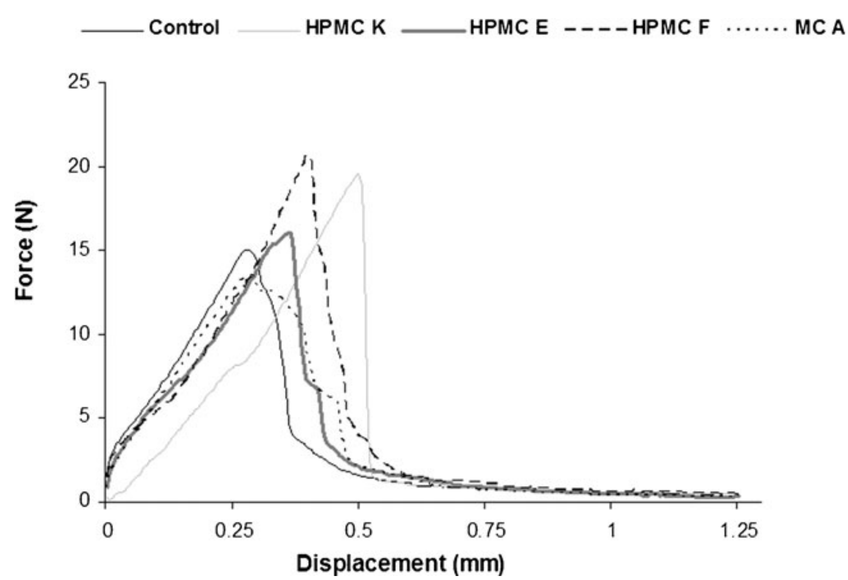

Fig. 3 Three-point break representative curve profiles of the control and fat-replaced biscuits

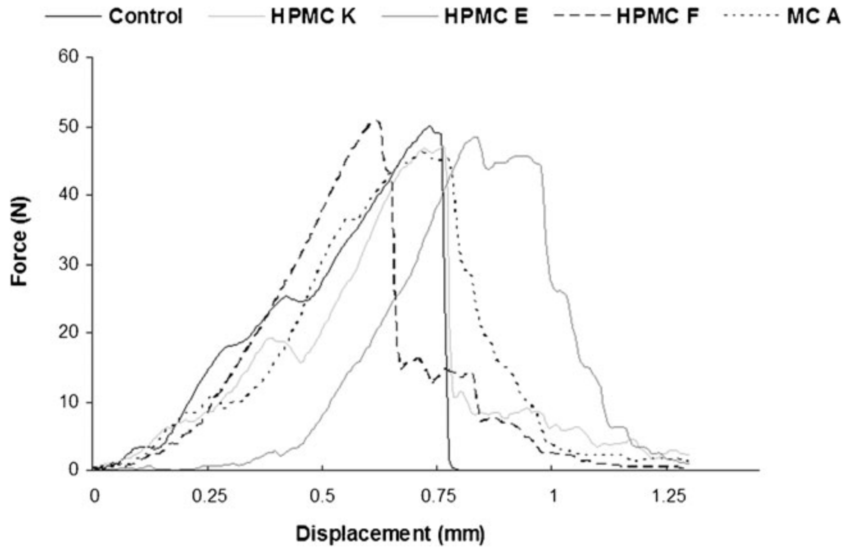

Fig. 4 Penetration representative curve profiles of the control and fat-replaced biscuits

water gives more flour protein hydration and more gluten formation, which in turn gives tougher dough and harder cookies (Manley 2000).

The texture results obtained in the cellulose emulsion biscuits indicate that the cellulose emulsions simulate the functionality of the shortening quite effectively. In general, the fact that the biscuit hardness did not increase significantly ($p>0.05$) implies that gluten development is not greater than in the control biscuit. This confirms that, although the water level in the emulsion biscuits is very high, this water is not readably available for protein hydration as can be seen in a_w values (Table 3) where no significant ($p>0.05$) differences were found among the cellulose and control biscuits.

Also, as in the case of the dough texture, the presence of the cellulose emulsion in itself exerts an effect on the biscuit texture, irrespective of its effect on the functionality of the other ingredients. MC and HPMC possess the property of thermogelling (Kobayashi et al. 1999 and Sanz et al. 2005). When the biscuit dough is baked, thermogelling causes a gel to form. It is probably the development of this gel-type texture during baking that is responsible for avoiding the hard texture normally found with fat reduction or replacement.

Figure 4 shows the results of the penetration test with the Volodkevich Bite Jaws, which imitate the force required to bite the biscuit (Laguna et al. 2011). In general, the biscuits containing cellulose ethers did not present significant ($p>0.05$) differences in maximum penetration force compared to those made with shortening (Table 3). Also, the presence of methoxyl groups in the biscuits made with the different cellulose ethers did not affect their hardness as no significant ($p>0.05$) differences were observed between the celluloses with the highest and lowest methoxyl group content (MC A and HPMC K, respectively). The same was found for hydroxypropyl substitution: there was no significant ($p>0.05$) difference in hardness between the biscuits with zero and medium substitution levels (MC A and HPMC K, respectively).

Consumer Sensory Analysis

The results for appearance, colour, texture, flavour, sweetness and overall liking for the different samples is shown in Fig. 5. The appearance of the biscuit with the greatest quantity of hydroxypropyl groups (HPMC E) was rated higher than that of the other samples with cellulose, although the difference

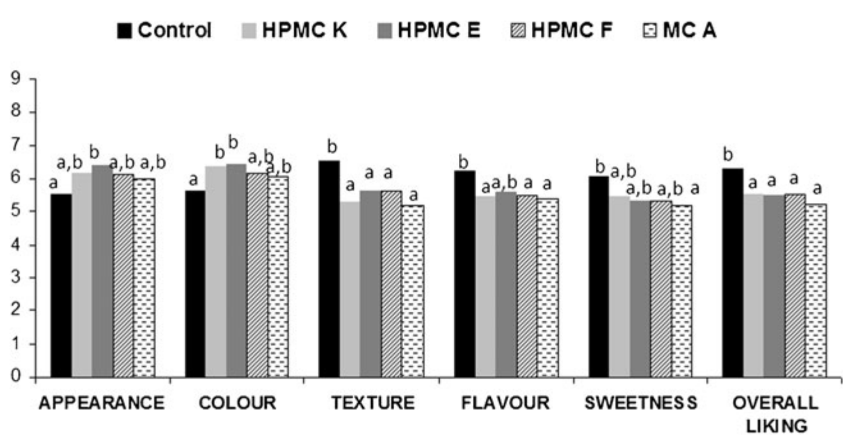

Fig. 5 Scores for sensory hedonic test of biscuits

was not significant ($p>0.05$). However, the liking for its appearance was significantly ($p<0.05$) higher than for the control. This formulation and the one with the next highest quantity of hydroxypropyl groups (HPMC K) also scored significantly ($p<0.05$) higher on colour (6.44 and 6.34, respectively) than the control. Even though the sugar content was the same in all the samples, the biscuits made with the methylcellulose emulsion (MC A—no hydroxypropyl group) were rated considerably lower on sweetness than the sample containing shortening. This could be an indication that methylcellulose may influence some aspects related to the perception of sweetness. Owing to the decisive role of fats in texture and flavour development in this type of product, these and overall liking were the attributes most affected by replacing the shortening with the cellulose emulsions. The texture of the control biscuits achieved the highest score (6.51) by a significant ($p<0.05$) margin, but the mean scores of all the biscuits with cellulose ethers were always over 5, indicating that they were acceptable to the consumers. In terms of flavour, the control biscuits were rated the highest (6.22), although the differences compared to those prepared with the HPMC with the highest percentage of hydroxypropyl groups (HPMC E) were not significant ($p>0.05$), unlike the differences between the control biscuits and all the other samples. The overall liking scores for the different samples showed that the consumers preferred the control biscuits to any of the others. However, the differences were very small (the maximum difference was 1.1/9 points) and the scores for all the biscuits containing cellulose ethers were always over 5.2. The difference in overall acceptance could be related mainly to the difference in the texture scores and the absence of a buttery aroma, which is not present in the biscuits made with the cellulose emulsions. In principle, however, this aspect could be solved by adding butter aromas.

Conclusions

The cellulose emulsions can be considered as a suitable trans-fatty acid-free fat replacer for shortening, which in addition reduced the final fat content of the biscuits by 33 %. The cellulose emulsions significantly ($p<0.05$) alter the dough texture, which becomes softer, more elastic and cohesive than in a traditional dough recipe prepared with shortening. Despite the biscuit dough being more elastic, the biscuit spreadability was higher in the cellulose emulsion doughs, which cannot be explained in terms of their elasticity properties but can be understood in relation to the greater softness of the dough due to the formation of a gel with the cellulose ethers. After baking, the texture of the cellulose emulsion biscuits was not significantly ($p>0.05$) different to that of the standard shortening biscuits, which reflects the suitability of the cellulose emulsion for replacing 100 % of the shortening. The similarity in texture properties between the two types of biscuits, despite their different fat contents, can be associated with the thermal gel formed by cellulose during baking, which simulates the softness in texture provided by fat. The degree of methoxyl and hydroxypropylmethyl substitution did not affect the dough or biscuit texture significantly ($p>0.05$). In general, the acceptability of trans-fatty acid-free fat biscuits was only slightly lower than that of the control biscuits.

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