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Edible coatings from cellulose derivatives to reduce oil uptake in fried products

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Abstract

Methylcellulose (MC) and hydroxypropylmethylcellulose (HPMC) were used in coating formulations to reduce oil uptake in deep-fat frying potato strips and dough discs. MC coatings were more effective in reducing oil uptake than HPMC ones. The effect of plasticizer addition (sorbitol) was also evaluated. The best formulations were 1% MC and 0.5% sorbitol for fried potatoes and 1% MC and 0.75% sorbitol for dough discs. For these formulations, oil uptake reduction was 40.6 and 35.2% for potato strips and dough discs compared to the uncoated samples; the increase in water content was 6.3 and 25.7%, respectively. Non-significant differences in texture of coated and uncoated samples were observed. Although instrumental color differences were detected, all samples were accepted by the non-trained panel.

Keywords: Edible coatings; Cellulose derivatives; Deep-fat frying; Oil-uptake; Doughnuts; Potatoes

Industrial relevance: In our fat conscious society the reduction of oil contents of deep fat fried products has been of industrial interest for many years. Oil sources, predrying and the applicational mass transfer barriers on the product surface were among the methods applied. This paper compares the effects of various cellulose derivatives and additionally the plasticizer effect of sorbitol on selected cellulose derivatives. Significant reduction of oil uptake (up to 41%) could be achieved without a detectable effect on sensory properties. Such coating procedures could lead to a dramatic impact on overall fat intake if applied to commonly consumed products such as french fries or chips.

1. Introduction

In deep-fat fried products, both health and sensory aspects should be addressed to meet consumer demand. Deep-fat frying is widely used to prepare tasty foods. The soft and moist interior together with the crispy crust are desirable characteristics of most fried foods.

Some fried products may contain fat up to 50% of the total weight (Pinthus, Weinberg & Saguy, 1993). Some of these lipids were not in the food before frying. For example, lipid content of French fries increases from 0.2 to 14%, lipid content may reach 40% in potato chips; raw fish with 1.4% reach 18% fat after frying (Smith, Clifford, Creveling & Hamlin, 1985; Mackinson, Greenfield, Wong & Willis, 1987). Thus, oil uptake in fried foods has become a health concern. High consumption of lipids has been related to obesity and other health problems like coronary heart disease. Thus, pressure to restrict and select the sources of fat and oils has increased. Besides, a new goal to find products and/or methods to reduce oil uptake during deep fat frying has appeared. Food coatings may become a good alternative to solve this problem. The effectiveness of a coating is determined by its mechanical and barrier properties, which depend on its composition and microstructure, and by the characteristics of the substrate, as well.

Several hydrocolloids with thermal gelling or thickening properties, like proteins and carbohydrates, have been tested to reduce oil and water migration (Debeaufort & Voilley, 1997; Williams & Mittal, 1999). Adding food hydrocolloids as dry ingredients is a practical way to lower oil uptake of deep-fat fried foods, since the addition does not change conventional production procedures (Meyers, 1990). Edible coatings at the surface

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of the foods comprise another possibility, but this technique has not been studied extensively. Mallikarjunan, Chinnan, Balasubramaniam and Phillips (1997) working with mashed potato balls reported a reduction, compared to uncoated balls, of 14.9, 21.9 and 31.1% in moisture loss and of 59.0, 61.4 and 83.6% in fat uptake for samples coated with corn zein, hydroxypropylmethylcellulose (HPMC) and methylcellulose (MC) films, respectively. Williams and Mittal (1999) also found that MC films showed the best barrier properties, because it reduced fat uptake more than hydroxypropylcellulose (HPC) and gellan gum films applied to a pastry mix. They also reported difficulties to evaluate potato products.

Cellulose derivatives, including MC and HPMC exhibit thermo-gelation. When suspensions are heated they form a gel that reverts below the gelation temperature, and the original suspension viscosity is recovered (Grover, 1993). These cellulose derivatives reduce oil absorption through film formation at temperatures above their incipient gelation temperature, or they reinforce the natural barriers properties of starch and proteins, especially when they are added in dry form (Meyers, 1990).

The objective of the present work was to apply coatings based on cellulose derivatives and plasticizer, to reduce oil uptake in French fried potatoes and pastry products, optimizing their formulations.

2. Materials and methods

2.1. Cellulose derivative suspensions

Cellulose derivatives (Methocel), K100LV and E15LV (two different hydroxypropylmethylcelluloses, HPMC) and A4M (methylcellulose, MC), were provided by Dow Chemical (USA). Concentrations of aqueous cellulose derivative suspensions of 1 and 2% were tested to select appropriate formulations for coating applications.

Plasticizer effect of sorbitol on the selected cellulose derivative formulations was analyzed. Sorbitol (Merck, USA) concentrations assayed in the suspensions were 0.25, 0.50, 0.75 and 1% (w/w).

2.2. Rheological characterization of cellulose derivative suspensions

Rheological characterization of the cellulose derivative suspensions was performed in a Haake RV2 (Haake, Germany) rotational viscometer, at controlled constant temperature (20 °C). A NV type sensor system of coaxial cylinders was used for all the measurements. Rheological curves were obtained after a stabilization time of 3 min at 20 °C. Shear stress was determined as a function of shear rate between 0 and 1382 s^{-1} with the following program: 3 min to attain the maximum shear rate, 1 min at the maximum shear rate and 3 min to attain 0 shear rate. Apparent viscosities were calculated at 64 (345.6 s^{-1}) and 128 rpm (691.2 s^{-1}).

2.3. Sample preparation and frying conditions

Samples of potato strips (0.7×0.7×5 cm) and commercial dough discs of wheat flour (Pillsbury, Argentina), 3.7 cm in diameter and 0.3 cm high, were dipped in the coating suspensions for 10 s and immediately fried.

Coated and uncoated (control) samples were fried in a controlled temperature deep-fat fryer (Yelmo, Argentina) filled with 1.5 l of commercial sunflower oil (AGD, Córdoba, Argentina). Oil composition was 99.93% lipids, with 25.71% mono-unsaturated and 64.29% poly-unsaturated fatty acids. Used oil was replaced by fresh oil after four frying batches. In each batch six potato, samples or four dough discs were fried.

Different constant frying temperatures were tested to select the working frying conditions according to sample characteristics. These temperatures ranged between 150 ± 0.5 and 170 ± 0.5 °C for dough and between 170 ± 0.5 and 190 ± 0.5 °C for potatoes; frying times ranged between 2 and 5 min in both cases. Optimum time-temperature frying conditions were determined by sensory analysis; a non-trained panel judged color, flavor, texture and overall appearance.

2.4. Microscopy observations

Coating integrity was analyzed by stereomicroscopy observation (Leitz Ortholux II, Germany), staining sample surfaces with toluidine blue. Scanning electron microscopy (SEM) of coated and uncoated samples was performed with a JEOL JSMP 100 scanning electron microscope (Japan). Coated pieces were mounted on bronze stubs using double-sided tape and then coated with a layer of gold (40–50 nm). All samples were examined using an accelerating voltage of 5 kV.

2.5. Water content

Water content (WC) was determined measuring weight loss of fried products, upon drying in an oven at 110 °C until constant weight. Relative variation of water retention% (WR) in the coated product relative to the uncoated one was calculated as follows:

$$WR = \left(\frac{WC\ \text{coated}}{WC\ \text{uncoated}} - 1 \right) \times 100 \tag{1}$$

where: WC is the water content of the samples. For each coating formulation, results were obtained using all the samples from two different batches.

2.6. Lipid content

Lipid content (LC) of fried products was determined on dried samples using a combined technique of successive batch and semicontinuous Soxhlet extractions. The first batch extraction was performed with petroleum ether/ethylic ether (1:1) followed by a Soxhlet extraction with the same mixture and another Soxhlet extraction with n-hexane. Oil uptake relative variation% (OU) in the coated product relative to the uncoated one was calculated as follows:

$$OU = \left(\frac{LC\ \text{coated}}{LC\ \text{uncoated}} - 1\right) \times 100 \quad (2)$$

where: LC is the lipid content of the samples. For each coating formulation, results were obtained using all the samples from two different batches.

2.7. Instrumental analysis

2.7.1. Colorimetric measurements

Assays were carried out with a Minolta colorimeter CR 300 Series (Japan) calibrated with a standard ($Y=93.2$, $x=0.3133$, $y=0.3192$). The Hunter scale was used, lightness (L) and chromaticity parameters a^* (red–green) and b^* (yellow–blue) were measured. Samples were analyzed in triplicate, recording four measurements for each sample.

2.7.2. Texture analysis

Breaking force of samples was measured by puncture test using a texture analyzer TA.XT2I—Stable Micro Systems (Haslemere, Surrey, UK) with a 5 kg cell. Samples were punctured with a cylindrical plunger (2 mm diameter) at 0.5 mm/s. Maximum force at rupture was determined from the force-deformation curves. At least 10 samples were measured in each assay. Samples were allowed at reach room temperature before performing the tests.

2.8. Volume and density measurements

Dough sample volume was measured after frying by immersing the samples in a graduated cylinder filled with linseeds. Each sample density was calculated by dividing the sample weight by the shifted volume. Assays were performed in triplicate.

2.9. Sensory analysis

French-fries and fried dough discs coated with the selected formulations were evaluated by a non-trained sensory panel of 22 members. Two triangle tests were performed to determine if consumers could distinguish between coated and uncoated samples. Each sample was randomly numbered and presented to the panel member with the instructions to pick the two equal samples out of three. A hedonic panel was also performed with the same panellists, who evaluated texture, color, flavor and overall characteristics. A hedonic 4-point scale was used, 1=dislike, 2=acceptable, 3=like and 4=like very much.

Table 1
Apparent viscosities of modified cellulose suspensions

System	Apparent viscosity (mPa.s)	
	at 345.6 s^{-1}	at 691.2 s^{-1}
A4M 1%	138.1±5.2[a]	105.0±0.8
K100LV 2%	67.5±1.3	66.2±0.6
E15LV 2%	15.3±0.4	14.6±0.2

[a] Mean±S.D.

2.10. Statistical analysis

Systat-software (SYSTAT, Inc., Evanston, IL, USA, 1992) version 5.0 was used for all statistical analysis. Analysis of variance (ANOVA) and Fisher LSD mean comparison test were applied. The significance levels used were 0.05 and 0.01.

3. Results and discussion

3.1. Rheological characterization of the coating suspensions

According to manufacturer description, A4M is a modified cellulose that contains only methyl groups as substituents allowing stronger interactions between hydrocolloid chains; thus, it should yield high viscosity solutions even at concentrations of 1%. K100LV and E15LV are hydroxypropylmethyl derivatives of celluloses containing both substituents methyl and hydroxypropyl groups. In these cases, the interaction between chains may be hindered by steric impediment. Thus, K100LV should yield medium viscosity solutions and E15LV with higher percentage of hydroxypropyl groups and more steric impediments should yield lower viscosity solutions. On account of this and to attain a performance of these hydrocolloids similar to A4M, the assayed concentrations of K100LV and E15LV solutions were higher than that of A4M; however, concentrations above 2% were very difficult to solubilize.

Apparent viscosities of cellulose solutions at 20 °C at two different shear rates (345.6 and 691.2 s^{-1}) are shown in Table 1. Apparent viscosities at each shear rate were significantly different among the different cellulose derivatives. Even though concentrations of K100LV and E15LV solutions doubled that of A4M, apparent viscosity of A4M was markedly higher.

3.2. Selection of frying conditions

Because frying conditions determine sensory characteristics and consumer acceptability of fried products,

Table 2
Characterization of potato fries coated with different formulations

Coating formulation (without plasticizer)	Relative variation of oil uptake (OU), (%)[a] [Eq. (2)]	Relative variation of water retention (WR), (%)[b] [Eq. (1)]	Surface color parameters		
			L	*a**	*b**
Control	–	–	55.46 ± 3.56[c]	2.27 ± 1.01	30.59 ± 1.51
1% MC (A4M)	-15.53 ± 0.79	2.14 ± 0.49	58.42 ± 2.93	4.58 ± 1.89	36.64 ± 2.23
2% K100LV	-6.30 ± 0.21	0.49 ± 0.21	62.02 ± 3.45	2.28 ± 1.01	30.59 ± 1.52
2% E15LV	-7.60 ± 0.74	1.00 ± 0.15	62.51 ± 3.05	-1.64 ± 0.64	28.70 ± 1.97

[a] Oil content of control sample $= 4.43 \pm 0.74$ g oil/100 g (dry basis).
[b] Water content of control sample $= 62.62 \pm 0.92$ g water/100 g (dry basis).
[c] Value $\pm$ S.D.

both instrumental color and sensory characterization were performed to select time–temperature conditions.

Instrumental surface color showed no significant differences ($P > 0.05$) between French fries processed 5 min at 170 °C or 4 min at 180 °C and for dough discs processed between 2.5 min at 160 °C and 3 min at 150 °C. However, sensory analysis (color, flavor, texture and overall appearance) determined that 4 min at 180 ± 0.5 °C for French fried potatoes and 3 min at 150 ± 0.5 °C for dough discs were the best frying conditions. Accordingly, these were the selected operative conditions for further determinations.

3.3. Selection of the cellulose derivative for coating formulation

The cellulose derivative was selected from experiments done with French fries. Water and oil contents of the control sample were 62.62 ± 0.92 g water/100 g (dry basis) and 4.43 ± 0.74 g oil/100 g (dry basis), respectively.

Coatings with cellulose derivatives without plasticizer applied on potato slices reduced oil uptake and led to a higher retention of moisture content during deep fat frying (Table 2). As water content in the coated product was higher than in the uncoated one the WR was always positive and higher for MC than for the HPMC coatings. The oil uptake was always negative because the lipid content of the coated sample was lower than the uncoated one. In the present work, MC coating was selected because it showed the highest oil uptake reduction compared to HPMC coatings. This could be attributed to the differences in suspension viscosities, which is related with the covering capacity of coatings. Besides, MC coatings showed, as seen by microscopic observations, a better adhesion to the fried products than the other coatings, even though the presence of cracks were detected in all cases. HPMC coatings did not show noticeable differences with regard to oil uptake; the presence of hydroxypropyl groups may limit film-forming capacity through steric hindrances. Mallikarjunan et al. (1997) working with potato balls found that MC coatings have better moisture barrier performance than HPMC ones, due to the lower hydrophilic character of MC. Besides, Holownia, Chinnan, Erickson and Mallikarjunan (2000) reported that MC and HPMC films applied on chicken strips decreased oil uptake and the degradation of frying oil, extending thus the useful life.

Coating presence significantly ($P < 0.05$) modified surface color parameters of potato slices (Table 2). Chromaticity parameter *a** of samples with different coatings and the uncoated samples were significantly different ($P < 0.05$). Even though instrumental color parameters showed differences, all samples were accepted by the non-trained panel. Sensory analysis and *L* values (Table 2) showed that control samples were darker and more opaque than coated samples.

3.4. Microscopy observation

Staining with toluidine blue only helped to visualize coated dough samples under light microscopy; the similar chemical structures of the potato matrix and cellulose derivatives did not allow to effectively differenciate the coating in French fries. Fried samples with unplasticized coatings showed cracks that may reduce barrier properties of the coating (Fig. 1a). Mallikarjunan et al. (1997) attributed the reduction in oil uptake and moisture loss to the formation of a protective layer on the surface of the samples during the initial stages of frying due to thermal gelation above 60 °C. This protective layer inhibits the transfer of moisture and fat between the sample and the frying medium. Coating integrity is an important factor because the presence of cracks may reduce barrier properties of coatings and may limit coating applications (Donhowe & Fennema, 1993). In the case of frying applications coating integrity also depends on the substrate. While potato fries almost maintained their shape and volume after frying, dough discs increased their volume and modified the shape. In

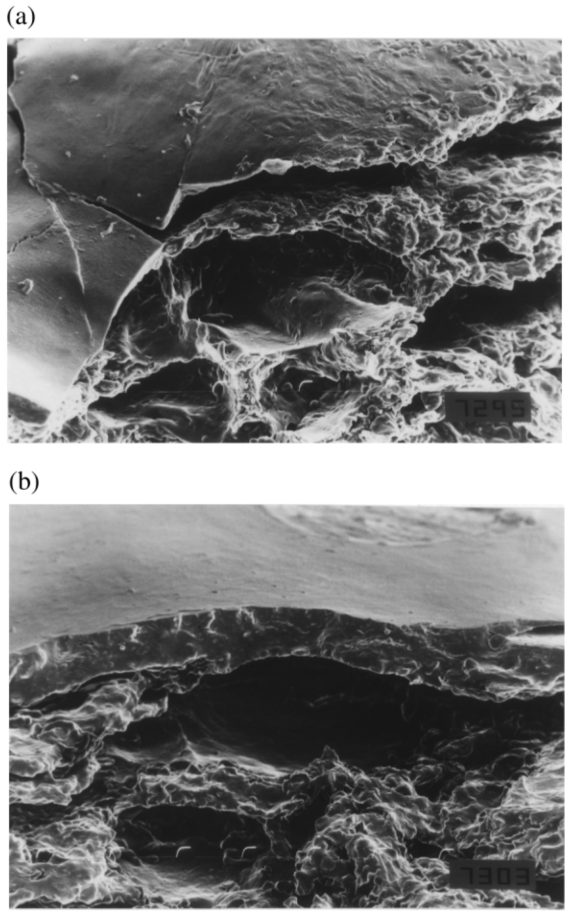

Fig. 1. Micrographs of fried dough discs coated with 1% methylcellulose (MC). (a) without plasticizer and (b) with 0.75% sorbitol. Magnification: 100 μm between marks.

the present work, observations by both SEM (Fig. 1a) and stereomicroscope of stained dough discs showed cracks in the coatings without plasticizer, evidencing the fragility of the coating structure. Thus, plasticizer addition was necessary to improve coating integrity and barrier properties.

3.5. Effect of coating formulation on oil absorption and water retention

As shown by SEM analysis, addition of plasticizer (sorbitol) to MC coatings was necessary to achieve coating integrity (Fig. 1b). A similar trend was observed by Rayner, Ciolfi, Maves, Stedman and Mittal (2000) working on deep-fat fried potato discs coated with plasticized soy protein films. Formation of a uniform coating on the surface of the sample is essential to limit mass transfer during frying (Huse, Mallikarjunan, Chinnan, Hung & Phillips, 1998).

Sorbitol addition improved barrier properties of coatings by decreasing oil content and increasing moisture retention compared to control and coated samples without plasticizer. ANOVA analysis ($P<0.05$) showed that the most effective sorbitol concentrations to reduce oil uptake were 0.5% for potato strips and 0.75% for dough discs (Figs. 2 and 3). Considering that the plasticizer increases the elasticity of the coating (Donhowe & Fennema, 1993) and the dough discs expanded during the frying process, a higher sorbitol concentration was required for dough samples. Similarly, Rayner et al. (2000) reported that the performance of soy protein film applied on dough discs increased by the addition of glycerine as plasticizer, reducing the food fat uptake.

Dough discs coated with MC and 0.75% sorbitol showed a 35.2% reduction of oil absorption and a 25.7% increase of moisture retention compared to control samples (Fig. 2a,b). For potato strips coated with MC and 0.5% sorbitol oil absorption decreased 40.6% and moisture retention increased 6.3% compared to control samples (Fig. 3a,b). Pinthus et al. (1993) reported that the addition of methylcellulose in dough formulation reduced significantly the oil uptake of doughnuts in the case of dry addition.

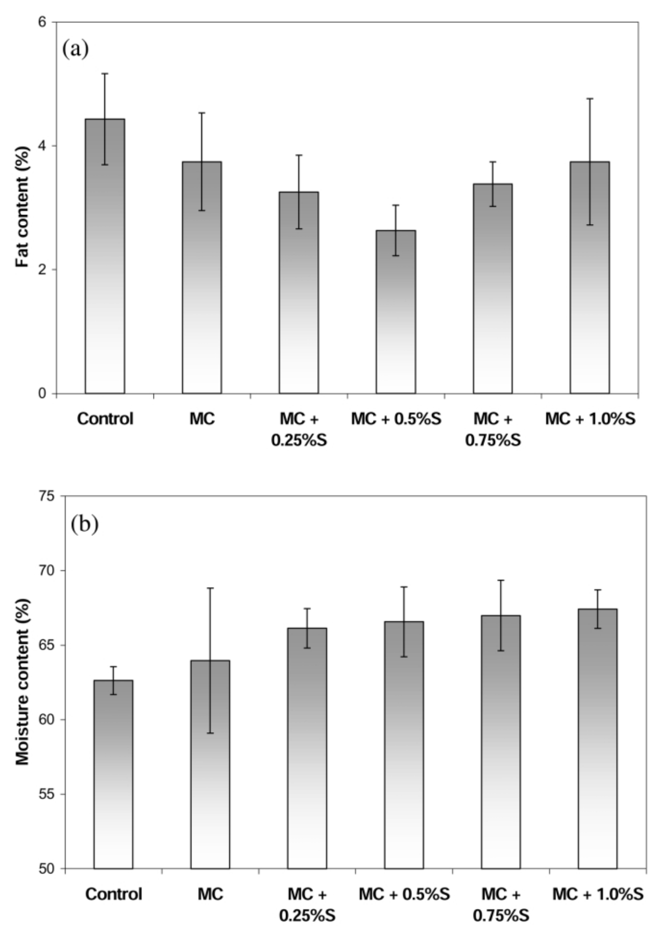

Fig. 2. Effect of coating formulation on fat and moisture content of coated and control (uncoated) fried potatoes. (a) Fat content and (b) Moisture content. Coating formulation: MC = 1% methylcellulose, S = sorbitol.

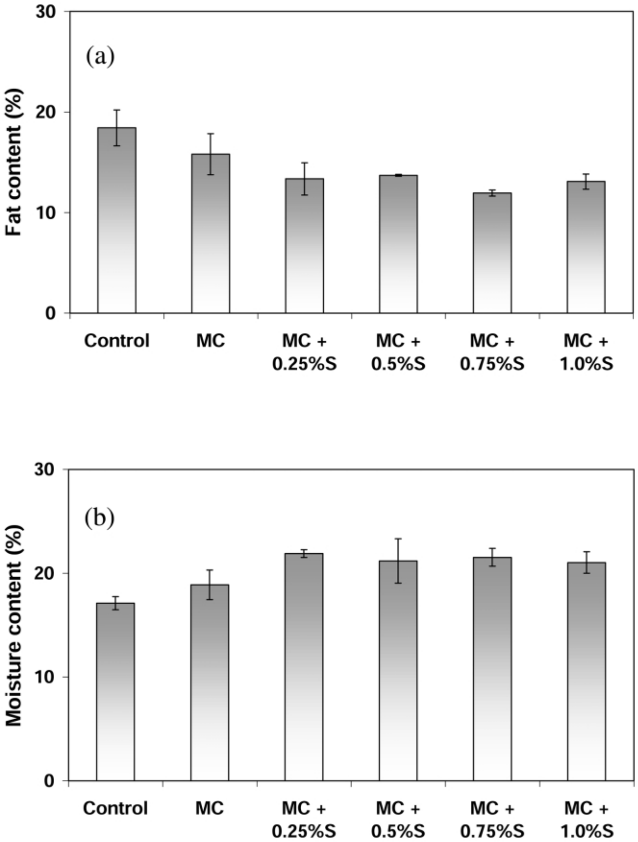

Fig. 3. Effect of coating formulation on fat and moisture content of coated and control (uncoated) fried dough discs. (a) Fat content and (b) Moisture content. Coating formulation: MC = 1% methylcellulose, S = sorbitol.

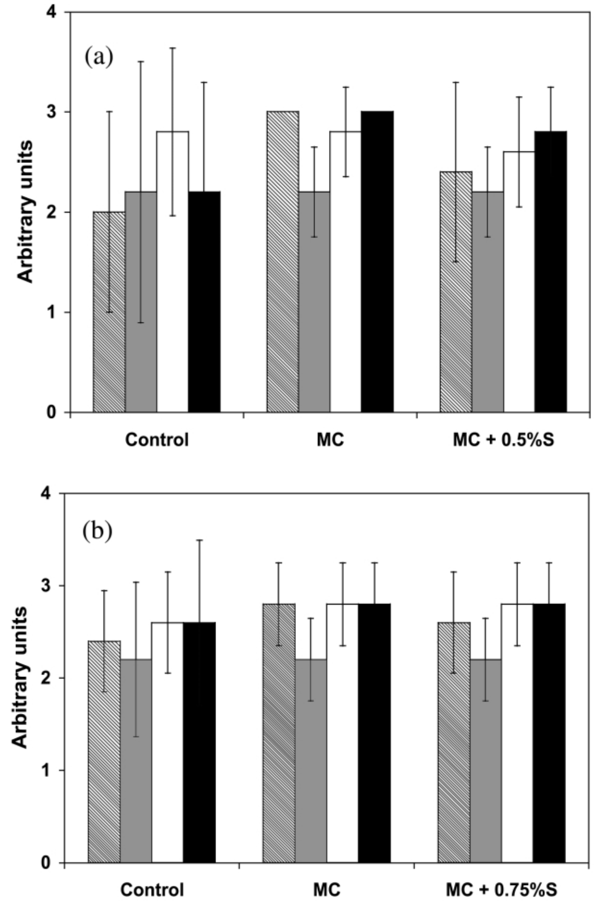

Fig. 4. Sensory evaluation of deep-fat fried samples, (a) French fries potatoes; (b) dough discs. ▧ Color, ▒ Texture, ☐ Taste, ■ Overall characteristics.

3.6. Sensory analysis

The triangular test showed non-significant differences ($P > 0.05$) between samples coated with MC and sorbitol and the uncoated controls for both fried products. Fig. 4a,b shows the results for the hedonic test; panellists did not reject any sample; in all cases, scores were higher than two (acceptable). Texture was the lowest scored parameter (2.2) with regard to color and flavor, however, texture scores of coated samples were similar to control ones. Flavor scores of coated samples were the highest and similar to the control values, these results were of great significance because no off flavors were detected considering the presence of the coating.

Mallikarjunan et al. (1997) reported that HPMC coatings improved sensory attributes of fried chicken

Table 3
Instrumental texture and color parameters of fried dough discs and potato strips

Sample	Formulation	Breaking force (N)	Surface color (Hunter units)		
			L	*a**	*b**
Dough discs	Control	6.69 ± 2.97[a]	54.83 ± 3.85	−2.11 ± 2.54	33.67 ± 2.33
	1% MC[b]	4.81 ± 1.53	61.68 ± 3.34	−7.15 ± 1.85	31.62 ± 2.31
	1% MC + 0.75% S[c]	5.33 ± 1.58	62.58 ± 1.62	−10.03 ± 0.62	27.77 ± 1.78
Potato strips	Control	2.57 ± 0.64	51.09 ± 3.62	6.21 ± 2.39	36.22 ± 1.68
	1% MC	2.77 ± 0.44	52.73 ± 4.08	4.32 ± 2.58	34.92 ± 1.86
	1% MC + 0.5% S	2.66 ± 0.30	46.91 ± 3.58	8.86 ± 1.78	33.29 ± 3.29

[a] Value ± S.D.
[b] MC = methylcellulose.
[c] S = sorbitol.

nuggets and marinated chicken strips, even more when HPMC was incorporated into the breading mix.

3.7. Instrumental analysis

Table 3 shows breaking force results for dough discs and potato strips with and without coatings. Coating did not significantly ($P>0.05$) modify texture of fried products. Instrumental results of breaking force agree with sensory analysis data. Similar results were obtained by Rayner et al. (2000) working on deep-fat fried potato discs coated with plasticized soy protein films. Besides, Funami, Funami, Tawada and Nakao (1999) working on doughnuts found that MC addition had no effect on breaking stress of the samples.

After frying, dough discs showed a volume increase that was quantified by the linseed method. Samples coated with MC and sorbitol showed a significantly ($P<0.05$) lower volume increase than uncoated samples. Samples coated with MC solutions plasticized with 0.5% sorbitol showed a higher density value (0.95 ± 0.05 g/ml) than the uncoated samples (0.70 ± 0.05 g/ml). With regard to volume, samples coated with MC without plasticizer did not differ significantly ($P>0.05$) than those of uncoated ones. This could be attributed to the more elastic layer of coating that limits the development of the dough network (Normen, Rovedo & Singh, 1998).

With regard to color, potato strips did not show significant differences ($P>0.05$) between uncoated samples and those with unplasticized coatings (Table 3). However, for dough discs significant differences ($P<0.05$) in lightness and chromaticity a^* parameter were found between the uncoated samples and those with unplasticized coatings. Anyway, all samples were accepted by the sensory panel.

Sorbitol addition showed a highly significant ($P<0.01$) effect on chromaticity parameters a^* and b^* for both potato and dough fried samples. In the case of lightness, the presence of sorbitol was significant ($P<0.01$) only for potato slices (Table 3). Samples coated with MC and sorbitol showed a lighter color which could be associated to a lower cooking time even though all samples were cooked for the same time period. The panellists did not detect flavor or texture differences between coated and control samples.

4. Conclusions

MC coatings were more effective in reducing oil uptake than HPMC ones, and it was the cellulose derivative selected for coating formulations. Sorbitol addition was necessary to maintain coating integrity and improve barrier properties. The most effective coating formulations were 1% MC and 0.75% sorbitol for dough discs and 1% MC and 0.5% sorbitol for potato strips. For these formulations, oil uptake reduction was 35.2 and 40.6% for dough discs and potato slices, respectively, and the increase in water content of the same products was 25.7 and 6.3%, respectively.

All samples were accepted by the panellists, although color differences between coated and uncoated samples were detected by instrumental analysis. Coating application did not modify texture characteristics of fried samples. This is a favorable result since our goal was to incorporate the coating to decrease oil uptake without having a significant impact on the sensory characteristics of the fried products.

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