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Effect of modified celluloses on dough rheology and microstructure

M.J. Correa [a,*], M.C. Añón [a], G.T. Pérez [b], C. Ferrero [a,*]

[a] CIDCA – Facultad de Ciencias Exactas-UNLP-CCT, La Plata (CONICET), 47 Y 116, 1900 La Plata, Argentina
[b] Facultad de Ciencias Agropecuarias-UNC, Av. Valparaíso s/n, C.C. 509, 5000 Córdoba, Argentina

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ABSTRACT

The effect of different modified celluloses on dough microstructure and rheological characteristics was studied. Microcrystalline cellulose (MCC), carboxymethylcellulose (CMC) and two different types of hydroxypropylmethylcellulose (HPMC F4M and HPMC F50) were tested in a range of concentration from 0.25% to 1.5% (flour basis). Doughs were formulated without and with salt (2%w/w flour basis). Farinographic water absorption increased when hydrocolloids were incorporated and the highest values were obtained in mixtures without NaCl and when HPMCs were added. A linear relationship between the percentage increment in water absorption and the hydrocolloid level was observed within the assayed range of concentrations. The development time was markedly increased when CMC was added. CMC and HPMC did affect or not dough stability depending on the presence or absence of salt whereas the stability was not modified by MCC. Texture attributes and the rheometric parameter tan δ were analyzed through Principal Component Analysis (PCA). Two factors described the 88.9% of total variation, one of them composed by hardness, consistency, adhesiveness and tan δ and the other composed by resilience and cohesiveness. Hydrocolloids addition softened the dough, particularly when salt was absent. Samples with salt and with hydrocolloids exhibited more cohesive and less resilient characteristics. Rheological results were in agreement with the characteristics of gluten network studied by SEM since a diminished stability and softer dough could be associated with a more disrupted matrix.

1. Introduction

The ability of wheat dough for rendering a viscoelastic matrix is the reason for the unique characteristics of bread: increased volume and a spongy crumb. The quality of this matrix is related to gluten development, mainly depending on the quality and quantity of gliadins and glutenins, water absorption and the interaction between proteins and other flour components like starch and fibre. Besides, the incorporation of other ingredients can also induce variation: for example, sodium chloride addition diminishes water absorption, increases mixing time and also modifies dough characteristics like resistance to kneading (Lynch, Dal Bello, Sheehan, Cashman, & Arendt, 2009; Stauffer, 1998).

The use of additives like oxidants, enzymes, emulsifiers and hydrocolloids is a common practice to improve the breadmaking performance of an inferior flour or mixture of flours (Stauffer, 1998). In general, addition of hydrocolloids to dough has important consequences on breadmaking procedure: they require a supplementary addition of water and the interactions they establish with the other dough components lead to changes in rheological properties of dough. These changes can also vary the sensorial attributes of the final product, resulting in an impact on consumers' acceptability (Gómez, Ronda, Caballero, Blanco & Rosell, 2007). Even though numerous studies have been conducted about the effect of different types of hydrocolloids on dough characteristics (Collar, Andreu, Martínez, & Armero, 1999; Guarda, Rosell, Benedito, & Galotto, 2004; Leon et al., 2000; Rojas, Rosell, & Benedito, 1999; Rosell, Rojas, & Benedito de Barber, 2001; Shalini & Laxmi, 2007) and particularly on their interaction with gluten proteins (Ribotta, Ausar, Beltramo, & Leon, 2005). Modified celluloses have been relatively less explored than others if we consider the diversity of their chemical structure and functional properties. They are the product of chemical modifications of native cellulose. This polysaccharide, a linear polymer of β-glucose is insoluble, but the modified derivatives like microcrystalline cellulose (MCC), carboxymethylcellulose (CMC) and hydroxypropylmethylcellulose (HPMC) may have quite different properties (increased solubility, thermal gelation, thickening capacity) that make them adequate as food additives. Microcrystalline cellulose is obtained by the partial hydrolysis of native cellulose fibres rendering crystalline particles; these ones are mixed with CMC to obtain a more easily dispersible

* Corresponding authors. Tel./fax: +54 221 4254853.
E-mail addresses: mjcorrea@biol.unlp.edu.ar (M.J. Correa), cferrero@biol.unlp.edu.ar (C. Ferrero).

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product. CMC, an anionic polymer, is obtained by the partial substitution of hydroxyl groups in glucose unit with carboxylic groups, negatively charged. HPMCs have two types of substituent: hydroxypropyl and methyl groups that confer them a certain degree of hydrophobicity depending on the length of side chains. Because of this particular characteristic, HPMCs have the capacity to gel when they are heated (Grover, 1982; Keller, 1982; Thomas, 1982).

Among these celluloses, hydroxypropylmethylcellulose (HPMC) has been reported to improve specific volume and crumb texture of bread (Rosell et al., 2001) and also to increase the shelf life of partially baked bread (Barcenas & Rosell, 2006). A mechanism of interaction of hydroxypropylmethylcellulose with gluten proteins during thermal treatment has been proposed by Rosell and Foegeding (2007). Besides HPMC affects gelatinization and viscometric behavior of starch although the extent of the effect depends on the concentration (Bárcenas, De la O-Keller, & Rosell, in press) Carboxymethylcellulose (CMC) has been studied by several authors as an improver for fresh or frozen dough and in fibre enriched fresh breads (Angioloni & Collar, 2009; Armero & Collar, 1996; Dodić et al., 2007). Microcrystalline cellulose (MCC) has been much less studied in wheat dough and bread products.

Regardless the existent literature about modified celluloses in breadmaking, the comparative study of their effect on wheat dough comes out as an interesting subject not only from a practical point of view but also to contribute to the understanding of the mechanisms involved in the additive–dough interaction. Taking into account the different structural characteristics and hydrophilicity of modified celluloses, a different effect on dough rheology is expected, depending on their structure. The evaluation of this differential behavior through different types of assays would contribute to elucidate certain keys of their mechanisms of action. Besides, the influence of NaCl on the interaction between modified celluloses and gluten network has not been thoroughly studied.

The objective of the present work was to analyze the effect of the addition of different modified celluloses on gluten formation, rheology behavior and microstructure of wheat flour dough with and without salt.

2. Materials

For dough preparation, commercial wheat flour was used (Type 000, Código Alimentario Argentino, 2004). Flour protein content was 11.4% (Kjeldahl factor = 5.7), moisture content was 14.2%. Alveographic characteristics of flour were: $P = 96$ mm H_2O, $L = 93$ mm, $W = 326 \times 10^{-4}$ J. Its Falling Number (FN) was 486 s. This type of flour is normally used in Argentina for French type bread. This bread requires values of alveographic W greater than 280, while for molded bread, W values should be between 330 and 370 (Pantanelli, 2003).

The hydrocolloids employed were: microcrystalline cellulose (MCC, FMC Biopolymer, Philadelphia), carboxymethylcellulose (CMC, Latinoquímica Amtex SA, Argentina) and two different types of hydroxypropylmethylcellulose (HPMC F4M and HPMC F50, Dow Chemical Company, USA). HPMCs have different degree of methoxyl and hydroxypropyl substitution being for HPMC F4M 29.3% and 6.0%, respectively and for HPMC F50, 28.6% and 5.4%, respectively. Commercial designations for HPMCs are based on viscosity values determined in water at 20 °C, with a concentration of 2% gum according to ASTM method D1347 (ASTM, 1995). For the batches used in this work, viscosities were 4477 mPa s for HPMC F4M and 46 mPa s for HPMC F50. Commercial MCC contains 12%w/w of CMC for a better dispersion. Distilled water and commercial salt (NaCl) were used to prepare dough.

3. Methods

3.1. Rheological characterization

3.1.1. Farinographic assays

Flour and hydrocolloid blends were prepared without and with salt (2 g/100 g flour). In both cases, dry ingredients were pre-mixed and the farinographic assay was conducted according to the standard method (AACC, 2000) in a 300 g-Brabender equipment (Duisburg, Germany). Hydrocolloid levels used were 0.25%, 0.5%, 1%, 1.5%. The following farinographic parameters were determined: percentage of water to yield consistency of 500 BU (water absorption – A), time to reach up to 500 BU (development time – td), time that dough remains at a consistency of 500 BU (dough stability). Besides, the percentage variation of farinographic water absorption respect to control for mixtures without and with salt was calculated according to:

$$\% \text{ variation} = \frac{A - A_0}{A_0} \, 100 \qquad (1)$$

where A is the water absorption of the mixture and A_0 is the water absorption of the control sample.

The assay was made in duplicate.

3.1.2. Dough preparation for rheological assays

Dough for rheological assays was formulated without yeast, 2% NaCl and the amount of water according to farinographic absorption. Hydrocolloids were tested at two levels 0.5% and 1.5% (flour basis). Dough was prepared in a small scale kneader with planetary mixing action (Kenwood, Italy). Farinographic development time was applied for obtaining an optimum development of dough. Dough was then sheeted in an equipment where rods were manually adjusted and turned. Dough was laminated four times to improve gluten development, turning it 90° after each passage by the rods. After this procedure, dough was covered with a plastic film to avoid water losses, and allowed to rest for 15 min at room temperature.

For texture assays, dough was sheeted to 1 cm height and cut into small cylindrical pieces (3 cm diameter). For rheometric assays, cylindrical pieces of 3 cm diameter and 2 mm height were obtained from laminated dough. Doughs were prepared in duplicate.

3.1.3. Dynamic rheometry of dough

For oscillatory assays, samples were maintained refrigerated for 10 min before testing. Dynamic oscillatory tests were performed in a Haake RS600 controlled stress oscillatory rheometer (Haake, Germany) at 25 ± 0.1 °C, using a plate–plate sensor system with a 1.5 mm gap between plates. Serrated plates were used and semisolid Vaseline oil was applied to prevent the sample drying during testing. All samples were allowed to rest for 15 min between plates before measurements to allow dough relaxation. In order to determine the linear viscoelastic range of each sample, deformation sweep tests were performed at a constant frequency (1 Hz). Frequency sweep tests (from 0.005 to 100 Hz) at a constant stress (5 Pa) within the linear viscoelastic range were performed at 25 °C. Dynamic moduli G', G'' and tan $\delta(G''/G')$ were obtained as a function of frequency. G' is the dynamic elastic or storage modulus, related to the material response as a solid, while G'' is the viscous dynamic or loss modulus, related to the material response as a fluid. Tan δ is related with the overall viscoelastic response: low values of this parameter indicate a more elastic sample. Assays were performed on each dough in triplicate.

3.1.4. Texture profile analysis (TPA) of dough

Cylindrical samples (10 pieces) of 3 cm diameter and 1 cm high were obtained from dough. Dough texture parameters were evaluated using a TA.XT2i Texture Analyzer (STABLE MICRO SYSTEMS, Surrey, UK) with a software Texture Expert for Windows, version 1.2. Dough was submitted to two cycles of compression up to 40% of the original height with a cylindrical probe (diameter = 7.5 cm). Force time curves were obtained at a crosshead speed of 0.5 mm/s. Dough hardness, adhesiveness, consistency, cohesiveness and resilience were determined. Hardness is defined as the maximum force registered during the first compression cycle. Adhesiveness is the negative area obtained during the first cycle. Cohesiveness was determined as the ratio between the positive area of the second cycle and the positive area of the first cycle. Consistency was calculated as the area of first peak plus the area of the second peak. Resilience is calculated as the area during the withdrawal of the first compression, divided by the area up to the maximum of the first cycle. It is related with the instantaneous recovery.

3.1.5. Relaxation assays

In stress relaxation assays, a sample is compressed to a determined strain and the stress required to maintain the deformation is observed as function of time.

The TA.XT2i Texture Analyzer (STABLE MICRO SYSTEMS, Surrey, UK) was used to determine the stress relaxation tests. Cylindrical dough samples were compressed at 0.5 mm/s speed up to 40% and maintained compressed for 20 min. A cylindrical probe of 7.5 cm diameter was used. The force was recorded as a function of time and the relaxation curves were fitted with the following exponential equation.

$$\sigma = A_1 \exp\left(-\frac{t}{\lambda_1}\right) + A_2 \exp\left(-\frac{t}{\lambda_2}\right) + \sigma_0 \qquad (2)$$

where σ is the stress (force/area), σ_0 is the equilibrium stress, λ_1 and λ_2 are the relaxation times and A_1 and A_2 are the preexponential factors. This expression corresponds to two Maxwell elements in parallel plus a spring element, also in parallel (Steffe, 1996).

Assays were performed at room temperature in triplicate. Samples border were covered with a thin film of vaseline to avoid dehydration during the assay.

3.2. Dough physico-chemical characteristics

3.2.1. Wet and dry gluten

The Glutomatic apparatus (Perten Instruments, Sweden) was used for the determination of wet and dry gluten. The assays were performed according to a modification of AACC 38-12 (2000) A. This adaptation was implemented because the mixing time specified by the method was not enough to obtain the gluten development when hydrocolloids were present. The dough was prepared in Kenwood kneader and then 15 g were put in the mixing/washing chamber of the Glutomatic. The dough was kneaded for 5 s and washed for 5 min. A metallic sieve (80 μm aperture) was used. The other conditions were not modified.

3.2.2. Moisture content

Moisture content of dough was indirectly determined by air-drying in an oven at 135 °C for 2 h (AACC method 44-19, 2000). The assay was made in duplicate.

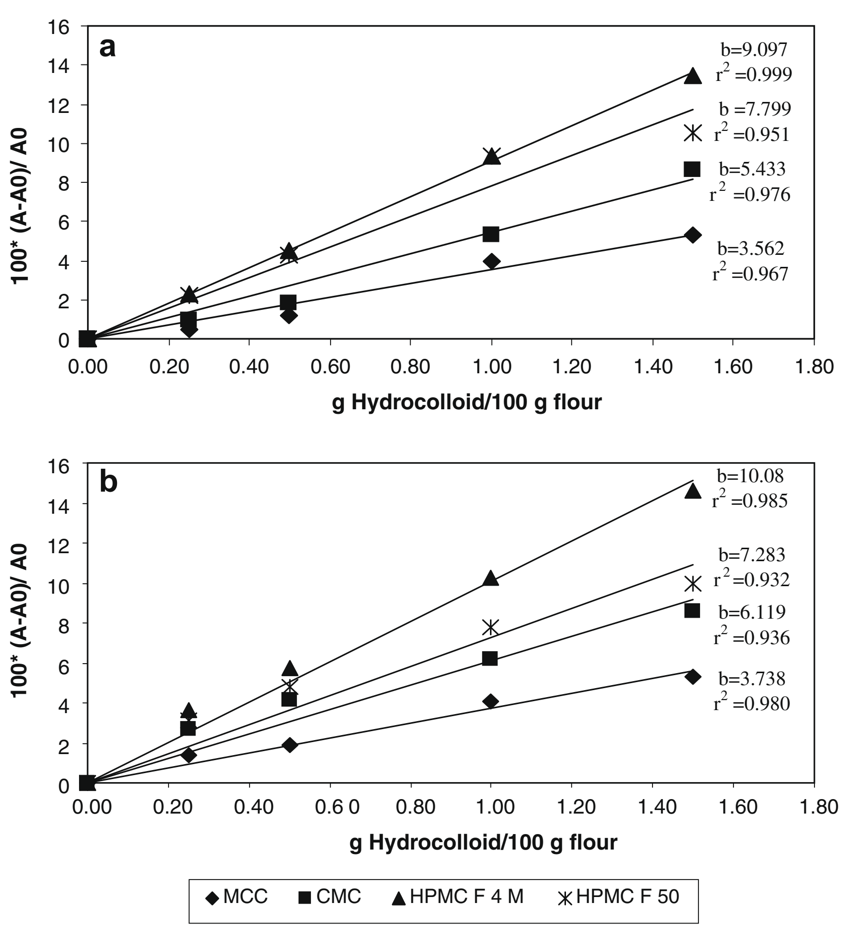

Fig. 1. Relative farinographic water absorption of flour hydrocolloid mixtures (a) with salt and (b) without salt. Linear fitting of data is shown, with *b* = slope.

3.3. SEM analysis of doughs

Scanning electron microscopy (SEM) of dough prepared with 1.5% of modified celluloses was performed. Dough samples were fixed in 10% glutaraldehyde, submerged in acetone solutions and then in acetone 100% to obtain complete dehydration. Samples were dried at the critical point and coated with gold. A scanning electron microscope (JEOL 35 CF, Japan) was used to observe the samples.

3.4. Statistical analysis

Statistical analysis and Principal Component Analysis (PCA) were carried out using Minitab 15 software (*Minitab Inc., 2006, USA*). *ANOVA was performed with the software Statgraphics plus for Windows 4.0.*

4. Results and discussion

4.1. Farinographic behavior of hydrocolloid-flour mixtures

It was observed that, the increase in water absorption caused by the increasing hydrocolloid addition followed a linear trend ($R^2 > 0.93$ in all cases), but the effect of the hydrocolloid was different when salt was present. In most cases, when salt was added the increase in % variation was smaller than without salt resulting in a lower slope (Fig 1a and b).

The farinograph development time (td) and stability of dough for mixtures with and without salt are shown in Figs. 2 and 3, respectively.

As a general trend, it can be observed that td and stability were increased in the presence of salt. Similar results were obtained by Galal, Varriano-Marston, and Jhonson (1978) and Wherle, Grau, and Arendt (1997).

The hydrocolloid that most affected the td was CMC, either in the absence or presence of salt. Both HPMCs modified the development time but in a lesser extent than CMC, being this effect appreciated at higher levels. The effect of MCC was noted at higher levels, but this fact could be attributed to the presence of CMC in this commercial gum.

In mixtures with NaCl, farinographic stability (Fig. 3a) was not significantly affected by MCC or CMC however HPMCs at levels higher or equal to 0.25% (depending on the type of HPMC) negatively affected stability.

A different effect was observed in mixtures without salt (Fig. 3b): the highest levels of CMC markedly reduced farinograph-

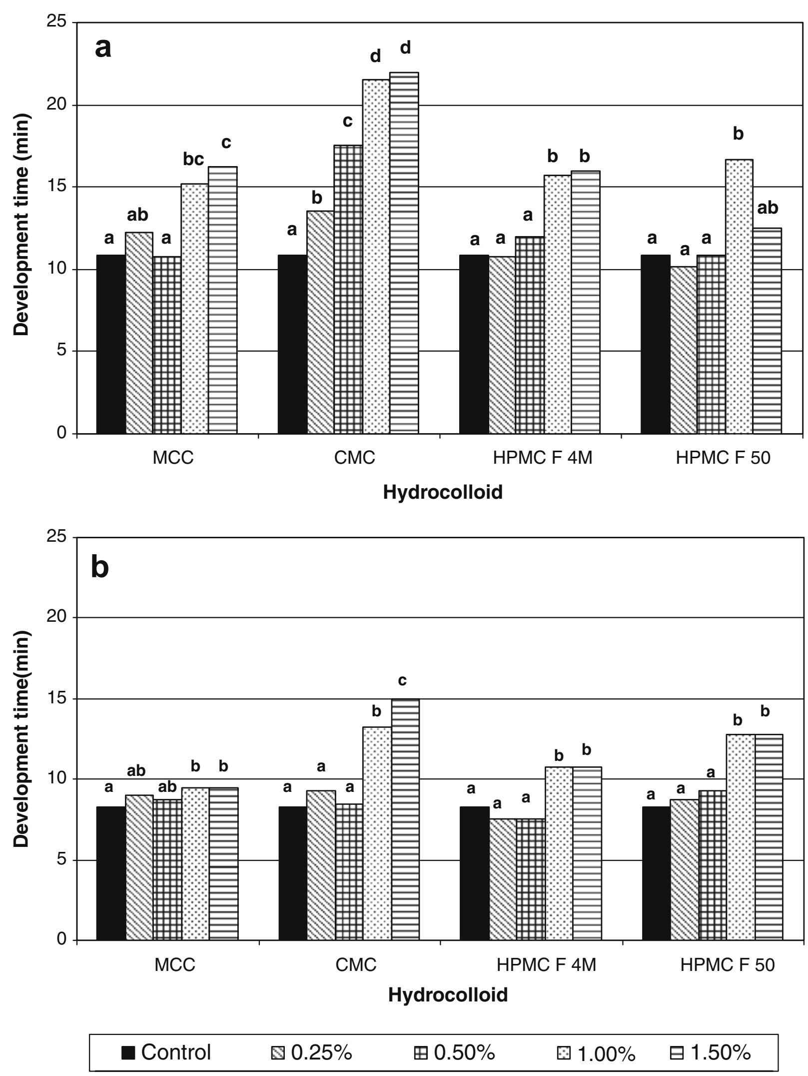

Fig. 2. Farinographic development time (min) for flour hydrocolloid mixtures (a) with salt and (b) without salt.

ic stability, but this parameter was not affected by HPMCs or MCC. NaCl was found to be an enhancer of water structure, thus promoting hydrophobic interactions (Kinsella & Hale, 1984). So, the most hydrophobic modified celluloses like HPMCs could interact with gluten proteins, rendering in this case a less stable network. In the absence of salt, this effect could not be observed. On the other hand, the interaction with charged molecules like CMC seemed to be favoured in the absence of salt.

4.2. Physico-chemical characterization of dough

Dough, prepared according to the methodology described in Section 3 showed different moisture contents since it was compared with the farinographic water absorption values, ranging from 42.7% for control dough with salt up to 45.7 for HPMC F4M without salt. For most of the samples, wet gluten values (WG) ranged between 29.0% and 32.1% and dry (DG) gluten values ranged from 9.9% to 11.3% (Table 1). The values for WG/DG were between 2.8 and 3.1 for all the samples studied. Comparing values with respect to control, WG values from dough with salt at the highest hydrocolloid level were significantly lower than those of the control sample. However, in any case, this difference was larger than 8%.

For samples without salt significant differences were found for WG, but the only remarkable ones were found in CMC and MCC dough at the highest level of hydrocolloid. For CMC samples, values

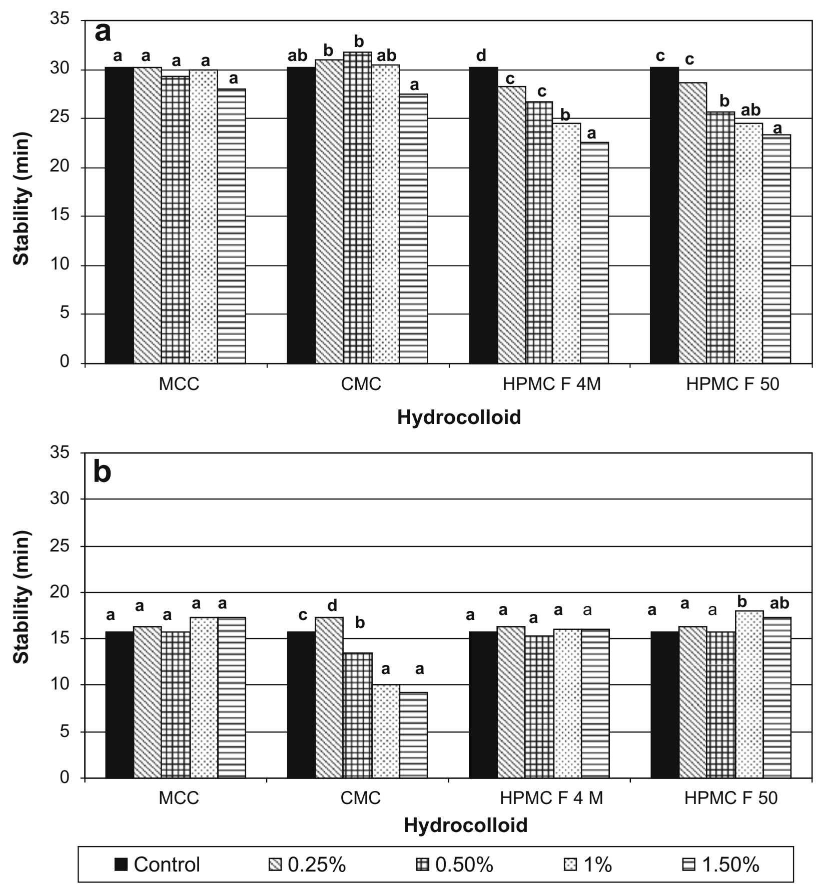

Fig. 3. Farinographic stability (min) for flour hydrocolloid mixtures (a) with salt and (b) without salt.

Table 1
Gluten values for samples with modified celluloses, with and without salt.

Samples	With salt		Without salt	
	Wet gluten	Dry gluten	Wet gluten	Dry gluten
Control	31.5 ± 0.6	10.4 ± 0.1	32.1 ± 0.3	11.0 ± 0.2
MCC 0.5%	31.8 ± 0.3	10.6 ± 0.3	31.1 ± 0.1	11.0 ± 0.0
MCC 1.5%	30.8 ± 0.2	10.3 ± 0.1	26.1 ± 0.6	9.3 ± 0.3
CMC 0.5%	31.0 ± 1.0	10.4 ± 0.1	30.8 ± 1.0	10.7 ± 0.6
CMC 1.5%	29.9 ± 0.6	10.4 ± 0.1	24.4 ± 0.3	8.6 ± 0.1
HPMC F4M 0.5%	30.7 ± 0.4	10.3 ± 0.3	31.4 ± 0.3	10.6 ± 0.3
HPMC F4M 1.5%	29.0 ± 0.2	9.9 ± 0.1	31.1 ± 0.2	10.7 ± 0.2
HPMC F50 0.5%	32.1 ± 0.5	10.4 ± 0.1	31.9 ± 0.4	11.3 ± 0.1
HPMC F50 1.5%	30.3 ± 0.3	10.1 ± 0.1	32.0 ± 0.2	11.1 ± 0.0

±SD.

for WG and DG were 24.4% (24% lower than control) and 8.6% (22% lower than control), respectively. For MCC samples, values were 26.1% (19% lower than control) and 9.3% (15.5% lower than control). Concerning CMC samples without salt, lower gluten formation was in agreement with a lower stability of dough. However, MCC addition led to a similar diminution of gluten formation without exhibiting a lower stability.

On the other hand, both HPMC gluten values were similar to control ones in samples with salt and in spite of this, stability was decreased when hydrocolloid levels increased (Fig. 3a).

These results show that the quantity of gluten obtained from dough with modified celluloses did not necessarily correlate with farinographic stability. Different mechanisms of negative interaction between hydrocolloids and gluten proteins may be involved in each case, thus a weaker network could be formed without a decrease in gluten values.

Bárcenas et al. (in press) found that HPMC (similar to that used in the present work) did not significantly ($P < 0.05$) modify WG and DG, but other gums (arabic gum and pectin) decreased gluten values suggesting a weakening effect on the gluten structure. These authors tested gums up to a level of 1% (flour basis) in the absence of salt. In our work, even though MCC, CMC and HPMC F4M exhibited significant differences only MCC and CMC at the highest levels showed a more pronounced effect on gluten parameters.

4.3. Rheological assays

4.3.1. Principal Component Analysis on textural and rheometric parameters

Texture and rheometric parameters of different wheat dough at 0.5% and 1.5% level of hydrocolloid were analyzed by Principal Component Analysis (PCA) (Fig. 4). PCA allows simplifying the analysis of several variables by combining them and obtaining a reduced number of parameters. In our case, variables were reduced to two components, being the total variation in all data explained up to 88.9% by PC1 (57.4%) and PC2 (31.5%). Component 1 was mainly defined by hardness, consistency, adhesiveness (with positive correlation) and the tangent of the phase angle (with negative correlation) whereas Component 2, mainly by cohesiveness (with positive correlation) and resilience (with a negative correlation).

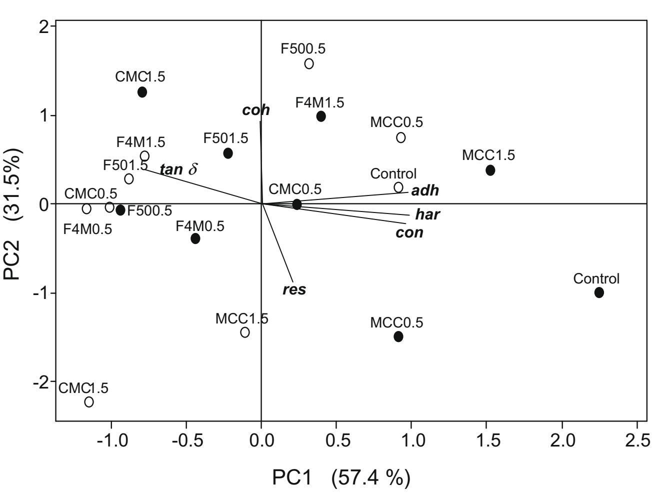

Fig. 4. Projection (Varimax rotation) of textural parameters (hardness, cohesiveness, consistency, adhesiveness, resilience) and tangent of the phase angle of different dough samples in the plane of the two principal components. Total variation explained by components: 88.9%, by PC1 57.4% and by PC2 31.5%. C: control; MCC: microcrystalline cellulose; CMC: carboxymethylcellulose; F4M; hydroxypropylmethylcellulose F4M; **F50:** hydroxypropylmethylcellulose F50. Numbers (0.5, 1.5) indicate concentration of hydrocolloid (%w/w), empty symbols indicate samples without salt, filled symbols indicate samples with salt. *adh*: adhesiveness, *coh*: cohesiveness, *har*: hardness, *con*: consistency, *res*: resilience, tan δ: tangent of the phase angle.

With respect to PC1, it can be seen that gum addition decreased adhesiveness, hardness and consistency, but increased tan $\delta(G''/G')$ value in respect of control. MCC exhibited the minor effect of softening. In all cases dough samples showed a solid viscoelastic behavior since $G' > G''$ (data not shown). When comparing samples with salt with respect to those with the same level of hydrocolloid and without salt, it was observed that salt addition increased hardness, consistency and adhesiveness, but decreased tan δ in most of the cases. A decreased value of tan δ was related to a less viscous behavior of dough. This effect of salt addition was in agreement with that reported by Larsson (2002) who found a significant increase in the value of the storage modulus when 1–2% NaCl was added to the dough.

Concerning PC2, both constituents of this factor, cohesiveness and resilience ("instant elasticity") exhibited opposite trends, indicating that a more cohesive dough has a smaller capacity of recovery after being subjected to strain. Samples with salt exhibited more cohesive and less resilient characteristics than the control one, except for the case of MCC samples at 0.5% hydrocolloid level. On the other hand, a more diverse behavior with respect to control was observed in the absence of salt for the PC2 component of samples.

Addition of salt in the CMC samples at the highest level of hydrocolloid (1.5%) led to a drastic change of cohesiveness and resilience. CMC dough with salt was more cohesive and less resilient than that without salt. This result was in agreement with the different farinographic stability found for these samples: when salt was absent, farinographic stability decreased. Cohesiveness was related to the degree of integrity of the samples; in the case of CMC and MCC samples without salt at 1.5% level, their lower cohesiveness was reflected in the gluten values obtained which were markedly low (Table 1).

Most samples with HPMCs, independently from gum concentration and salt addition, appeared to be grouped in a rather limited region of the graph, corresponding to softer and less adhesive dough. In general, HPMC F4M led to harder dough than that of HPMC F50. HPMC effect on viscoelastic properties of gluten has been studied by Rosell and Foegeding (2007) who found that HPMC induced a softening effect on dough, decreasing both storage and loss moduli in gluten – HPMC blends though no differences were found on tan δ value. In the present work, a similar effect of HPMC on these moduli was observed, but tan δ was increased (Fig. 4) indicating a change in the relative contribution of elastic and viscous moduli to the viscoelastic behavior of dough. Variations in tan δ indicated that structural changes had occurred in the gluten network.

4.3.2. Relaxation assays

Since an exponential decay of second order was necessary to explain the dough behavior it would indicate that not a single molecular mechanism was responsible for relaxation. The small polymer molecules relax rapidly whereas longer relaxation times have been associated to high molecular weight polymers (Dobraszczyk & Morgenstern, 2003). Results for both relaxation times (λ_1, λ_2) are shown in Table 2. When comparing control samples, it was evident that the presence of salt led to a marked increase on λ_1 with respect to samples without salt (293 min and 233 min, respectively). A higher relaxation time was related to a lower decay of stress as function of time. This would indicate a more pronounced solid-like behavior (Steffe, 1996).

In the presence of salt, all the samples with gums (except for MCC 1.5%) exhibited lower relaxation times with respect to con-

Table 2
Relaxation times (λ_1, λ_2) for samples with modified celluloses, with and without salt.

Samples	With salt		Without salt	
	λ_1 (s)	λ_2 (s)	λ_1 (s)	λ_2 (s)
Control	293 ± 7	7.9 ± 0.4	233 ± 7	6.3 ± 0.3
MCC 0.5%	279 ± 6	8.2 ± 0.7	248 ± 12	7.2 ± 0.8
MCC 1.5%	292 ± 13	7.9 ± 0.6	241 ± 11	7.5 ± 0.9
CMC 0.5%	250 ± 10	7.0 ± 0.5	266 ± 7	8.2 ± 0.8
CMC 1.5%	248 ± 10	6.6 ± 0.5	262 ± 13	8.3 ± 0.7
HPMC F4M 0.5%	249 ± 12	7.2 ± 0.7	220 ± 14	6.8 ± 0.7
HPMC F4M 1.5%	211 ± 7	5.4 ± 0.3	235 ± 19	6.6 ± 0.7
HPMC F50 0.5%	270 ± 10	7.6 ± 0.4	240 ± 15	7.1 ± 0.6
HPMC F50 1.5%	272 ± 19	6.7 ± 1.0	231 ± 6	6.8 ± 0.6

±SD.

trol, so they relaxed faster, indicating a more viscous behavior. These results are in agreement with the softening effect observed in Fig. 4 (decrease in hardness and consistency and increase in tan δ). However, in the absence of salt, relaxation times were not significantly different when compared to the control one except for CMC samples. In this case, higher relaxation values indicated a slower decay and so a more solid-like behavior. R^2 was higher than 0.966 in all cases.

4.4. SEM analysis

Fig. 5 shows representative SEM micrographs of the dough without and with hydrocolloids (at 1.5% level) with and without salt. Control samples exhibited a distinguishable gluten film (GF) structure, surrounding starch granules. Some gluten strands (GS)

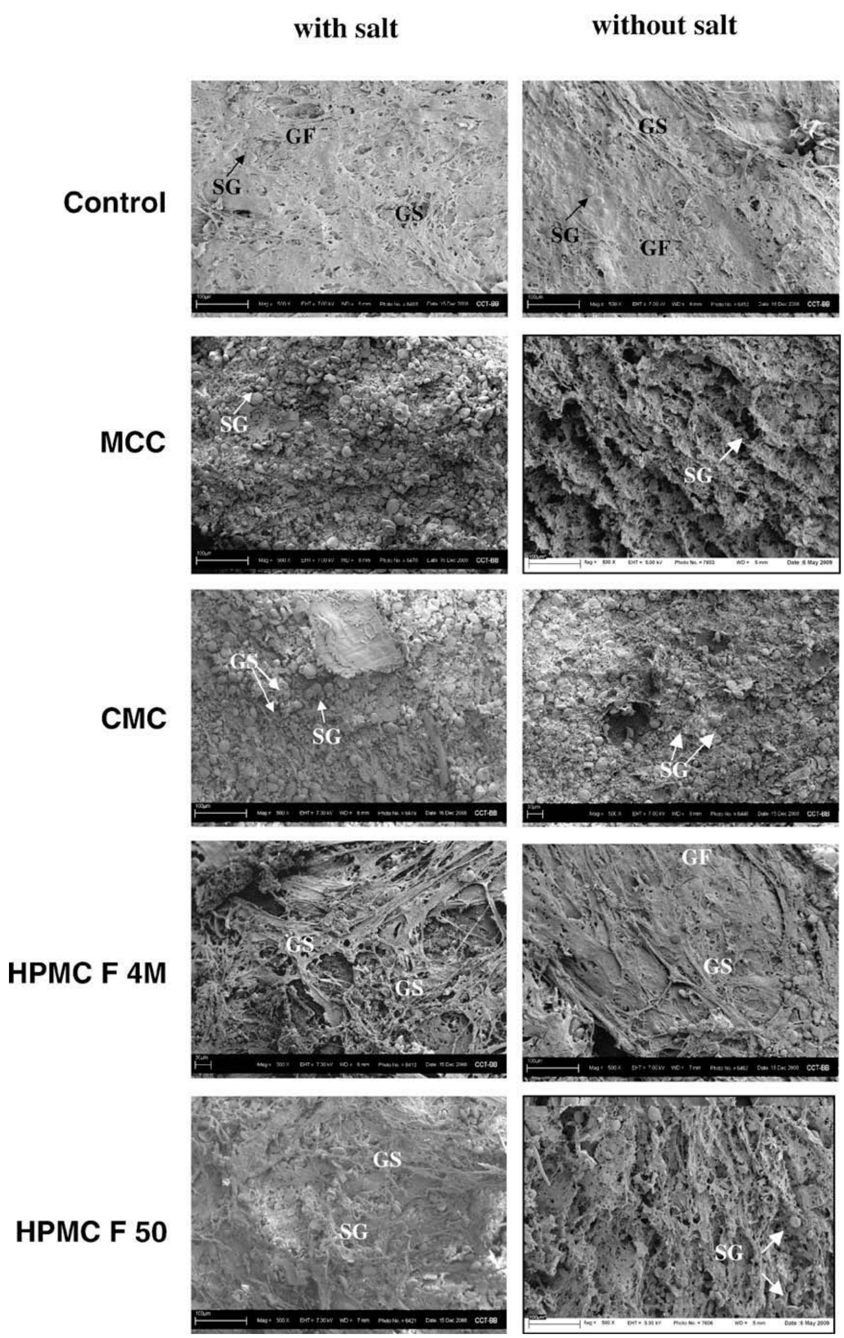

Fig. 5. SEM micrographs of dough samples with and without salt at the maximum hydrocolloid level (1.5%) SG: starch granule, GS: gluten strand; GF: gluten film.

were also evident. MCC samples showed a more disaggregated structure, particularly when salt was not added. In this case, an open, porous structure was observed. Starch granules were not completely covered by gluten and they could be easily identified. Samples with CMC did not exhibit a porous structure but there was not any gluten film formation as in control samples, so granules were not wrapped up. Gluten strands could be distinguished but they seemed shorter than in control samples. Comparing both CMC samples, that one without salt showed a more disrupted matrix; this lower quality of gluten network could be related with the diminished wet gluten value and the decrease in farinographic stability. In contrast, HPMC samples exhibited a more filamentous structure. The HPMC F4M sample with salt showed a pronounced filamentous aspect. Though some portions of gluten film could be observed, starch granules were not completely wrapped up. The same modified cellulose in the absence of salt showed a less filamentous aspect and more extensive gluten film structure. This sample had similar stability than the control sample, indicating a positive contribution to gluten network of this hydrocolloid. HPMC F50 rendered a less filamentous matrix than the other HPMC, gluten film portions and unwrapped granules could be seen.

5. Conclusions

Modified celluloses can change dough characteristics depending on their structure, concentration and the presence of salt. A less stable gluten network was obtained with a charged molecule like CMC in the absence of salt. On the other hand, more hydrophobic modified celluloses like HPMCs rendered a less stable network in the presence of salt. Gum addition decreased textural attributes like adhesiveness, hardness and consistency with respect to control for samples with and without salt. Samples with salt exhibited, in general, more cohesive and less resilient characteristics than the control ones. Mostly, when salt was present lower relaxation times were obtained in dough with hydrocolloids with respect to control whereas when salt was absent relaxation times were not significantly different to control one (except for CMC samples). Rheometric assays showed an increase in viscous behavior when hydrocolloids were added and a more elastic one behavior when salt was present, in agreement with the observed dough hardening in textural assays.

Macroscopic characteristics of dough were in agreement with microstructure as evaluated by SEM. Comparing both CMC samples, the one without salt showed a more disrupted matrix; this lower quality of gluten network can be related with the diminished wet gluten value and the decrease in farinographic stability. In contrast, HPMC samples exhibited a more filamentous structure.

These results indicate that dough rheology can be regulated by the addition of modified celluloses with different structure, taking into account the presence or absence of salt addition in dough.

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