1 **INFLUENCE OF DIFFERENT HYDROCOLLOIDS ON MAJOR WHEAT**
2 **DOUGH COMPONENTS (GLUTEN AND STARCH)**

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Abstract

The aim of this study was to determine the effect of three hydrocolloids from different sources (arabic gum, pectin and hydroxypropylmethylcellulose) on wheat dough major components (gluten and starch) using hydrated model systems. Gluten characteristics were evaluated concerning hydration properties (swelling, water retention capacity, water binding capacity), gluten quality (gluten index, the amount of wet and dry gluten), protein sodium dodecyl sulphate extractability, and rheological properties (elastic and viscous moduli); whereas the effect of hydrocolloids on wheat starch was assessed by recording the viscometric profile. Results showed that hydrocolloids tested affected in different extent to starch and gluten properties, being their effect dependent on the hydrocolloid type and also its concentration. All the hydrocolloids, with the exception of arabic gum, decreased the viscoelastic moduli during heating and cooling, yielding a weakening effect on gluten. Pectin mainly acted on gluten properties, varying gluten hydration, and also the quantity and quality of gluten. In addition, arabic gum acted primarily on the viscometric properties of starch. Therefore, hydrocolloid effect was greatly dependent on the hydrocolloid type, which defines its interaction with other components of the system.

Keywords: Gluten properties; starch properties; arabic gum, pectin; HPMC.

1. Introduction

In recent years, numerous studies have been focussed on the use of hydrocolloids as breadmaking ingredients in different types of breads or processes obtaining diverse response depending on the hydrocolloid used. Xanthan gum, alginate and locust bean gum affected the moisture content, texture and retrogradation enthalpy of pan bread crumb (Davidouet al., 1996). Carboxymethyl cellulose (CMC) and hydroxypropylmethylcellulose (HPMC) have been added to improve the quality of white and whole wheat breads (Armero and Collar, 1998), and also the effect of sodium alginate, κ -carrageenan, xanthan gum and HPMC on bread specific volume, hardness and moisture content have been evaluated (Rosell et al., 2001). Different hydrocolloids have been included in the formulation of partially baked bread for improving its quality. In fact, it has been reported that HPMC and κ -carrageenan affect the specific volume, hardness, moisture content and the staling of bread obtained from partially baked bread after being stored under sub-zero or low temperatures (Bárcenas et al., 2004; Bárcenas and Rosell, 2006). Guar gum has been also an effective improver, decreasing the crumb hardness and increasing the specific volume of bread obtained from frozen doughs (Ribotta et al., 2004). CMC and arabic gum have been incorporated with the same purpose (Asghar et al., 2006). Xanthan gum and guar gum modified the specific volume, moisture content and crust texture of breads obtained after thawing in the microwave frozen pan bread (Mandala, 2005). Even hydrocolloids (pectin, CMC, agarose, xanthan gum and β -glucan) functionality was greatly effective in the performance and quality of gluten free breads (Lazaridou et al., 2007) improving bread volume, hardness, porosity and elasticity of the crumb, and their sensorial acceptance.

Hydrocolloids improve the bread volume, softer texture and slower staling rate, in addition, hydrocolloids decrease the physical damage induced by ice crystals in breads obtained from frozen doughs or partially baked frozen bread. Likely, the most convenient hydrocolloid for those purposes is the HPMC (Bárcenas et al., 2004). Despite the extensive use of hydrocolloids in bakery products, only empirical studies have been reported, existing scarce information about hydrocolloids interaction with bread components (Collar, 2003; Funami et al., 2005; Muadklay and Charoenrein, 2007; Ribotta et al., 2005; Rosell and Foegeding, 2007; Zhou et al., 2008). Surely, the relationship of hydrocolloids with starch, gluten proteins and surrounding water molecules might be responsible of their effect on bread quality. A deep knowledge about hydrocolloids interaction within bread compounds would provide useful information for optimizing their addition. The aim of this study was to determine the effect of three hydrocolloids (arabic gum, high methoxylated pectin and HPMC) with different chemical structure on functional properties of gluten and starch using model systems.

2. Materials and methods

Vital gluten was a gift from Roquette (Keokuk, IL) and wheat starch was donated by Huici Leidan (Navarra, Spain). Hydrocolloids were obtained from different suppliers. Hydroxypropylmethylcellulose (HPMC, Demacol 2208 HK 4M) was obtained from Demacsa (México). This cellulose derivative has 22.0% methyl groups and 8.0% hydroxypropyl groups, and the viscosity of 2% solution in water is 4,500 cP at 20 °C.) Pectin (high-methoxil citric pectin, 60% substitution) was purchased from Laumann (México), and arabic gum (Makyspray F, type Seyal obtained by spray-drying) was provided by Colloides Naturels International (México).

2.1 Hydration properties of the gluten

Hydration properties, swelling, water holding capacity and water binding capacity, of the gluten dough were determined. Swelling, the volume of a known weight of gluten, was determined by mixing 5g (± 0.1 mg) of vital gluten with 100mL distilled water and allowing it to hydrate for 16h. Water holding capacity was the amount of water retained by the gluten without being subjected to any stress. It was determined by mixing 5g (± 0.1 mg) of vital gluten with 100mL distilled water and allowing it to hydrate for 16h; then gluten was weighted after removing the excess of water. Water binding capacity or the amount of water retained by the gluten after being subjected to centrifugation was measured as described by the [AACC method 61-02 \(1999\)](#). Hydrocolloids, when added, were mixed with the vital gluten using 0.002, 0.007 and 0.013 grams of hydrocolloid per gram of gluten. In the present study, hydrocolloid concentrations were selected within the range of levels commonly used in bakery products (0.1-1% flour basis) (Bárcenas et al., 2004; Lazaridou et al., 2007). Water adsorption substantially affects the gluten characteristics, thus unless otherwise described, all the assays were performed at the optimum water binding capacity of the dough, in order to determine the effect of the hydrocolloid without being the water content limiting factor. All determinations were made in triplicate.

2.2 Quantity and quality gluten parameters

Hydrated gluten balls were used for gluten parameters determinations (gluten index, wet and dry gluten). Gluten was obtained from 1 g of previously hydrated gluten ball, and wet gluten was determined after washing using a gluten washer (Glutomatic, Perten, Stockholm, Sweden). Gluten index was determined according to the approved method ([ICC method 155, 1994](#)) and dry gluten was assessed using the Glutork (Perten,

Stockholm, Sweden). To determine the effect of the hydrocolloids, solid powder was initially mixed to vital gluten using 0.002, 0.007 and 0.013 grams of hydrocolloid per gram of gluten. All determinations were made in triplicate.

2.3 Gluten protein extractability in SDS solution

To examine the interaction between the gluten proteins and the hydrocolloids, gluten vital/hydrocolloid blends vital (0.2 g) were prepared and extraction was carried out following procedure previously described by Rosell and Foegeding (2007). Hydrocolloids, when added, were mixed with the vital gluten using 0.002, 0.007 and 0.013 grams of hydrocolloid per gram of gluten. Again, concentrations were selected within the range of levels commonly used in bakery products (0.1-1% flour basis) (Bárcenas et al., 2004; Lazaridou et al., 2007). Gluten and hydrocolloids were mixed before the addition of the necessary distilled water to give final moisture content of 65% (w/w). Gluten balls were kept in a water bath at 25° C (unheated samples) or 85° C (heated samples) for 30 minutes. Temperatures were selected based on previous results, to guarantee that main starch and protein changes were finalized (Hayta and Schofield, 2004; Rosell and Foegeding, 2007). Thereafter, gluten balls were suspended in 20 mL of 2% (w/v) sodium dodecyl sulphate (SDS), mixed with a magnetic stirrer for 3 h and centrifuged at 16,000g for 15 min. The protein content of the supernatants was determined using the bicinchoninic acid (BCA) protein assay kit (Pierce, Cultek, Spain). Bovine serum albumin was used as standard protein. Values were calculated as the mean of three different extractions for each sample.

2.4 *Dynamic oscillatory tests*

Dynamic rheological measurements of the dough were determined on a controlled stress rheometer (Rheostress 1, Termo Haake, Germany) operated under strain control mode as described Rosell and Foegeding (2007). The measuring system consisted of serrated plate geometry (rough plate 35 mm diameter, 1 mm gap) to eliminate slippage during the test. Gluten dough was prepared by stirring with a spatula, 1 g of vital gluten with 10mL distilled water, and after centrifuging at 2,000g for 10 min; the supernatant was discarded. Hydrocolloids, when added, were mixed with the vital gluten (0.002, 0.007 and 0.013 grams of hydrocolloid per gram of gluten) before adding the distilled water. After centrifugation, samples consisted on rehydrated gluten up to the optimum water binding capacity. Gluten doughs were placed between the plates within 1 hour after rehydration and the test started after 15 minutes resting, so that residual stresses could relax. The rim of the sample was coated with vaseline oil in order to prevent evaporation during the measurements. Strain sweeps at 1 Hz frequency at 25 °C and 85 °C were determined in preliminary tests, and a strain of 4×10^{-3} was selected within the linear viscoelastic region. A frequency sweep from 0.01 to 10 Hz was performed at constant strain. Frequency sweep tests were performed from 0.01 to 10 Hz at 25°C, after heating up to 85°C at a heating rate of 1°C/min, and then after cooling till 25°C at a cooling rate of 1°C/min. Moduli (storage or elastic modulus G' and loss or viscous modulus G'') were determined as a function of frequency at 25 °C and 85 °C. Temperatures selection was based on previous results (Rosell and Foegeding, 2007).

2.5 *Viscometric properties*

The pasting properties were obtained with rapid visco analyser (RVA) (Newport Scientific, model 4-SA, Warriewood, Australia) by following the AACC Approved

Method No. 61-02 (AACC, 1995). RVA analyses were performed on wheat starch mixed with water and different hydrocolloids (HPMC, arabic gum and pectin). Viscosity was registered during a heating-cooling cycle: heating from 50 to 95° C in 282 s, holding at 95° C for 150 s and then cooling to 50° C. Each cycle was initiated by a 10 s, 960 rpm paddle speed for mixing followed by a 160 rpm paddle speed for the remainder of the data collection. Distilled water (25 ml) was added to 3 g of wheat starch or wheat starch-hydrocolloid blends placed into the aluminium RVA canister. The hydrocolloid effect was tested at three different levels (0.002, 0.007 and 0.013g of hydrocolloid per gram of wheat starch). Total weight added to the canister was kept constant at 28 g. Determinations were made in triplicate.

2.6 Statistical analysis

Multiple sample comparison was used for the statistical analysis of the results (Statgraphics V.7.1, Bitstream, Cambridge, MN). Fisher's least significant differences (LSD) test was used to differentiate means with 95% confidence, unless otherwise specified.

3. Results and discussion

3.1 Effect of hydrocolloids on the hydration properties and gluten properties

Hydration properties of the gluten (control) were not affected by the presence of arabic gum at any of the tested levels (0.002, 0.007 and 0.013g hydrocolloid per gram of gluten) (Table 1). Arabic gum has a branched but compact structure that could inhibit possible interaction between its polar groups with the peptide chains of the gluten.

The addition of HPMC induced a significant ($P<0.05$) effect on all the hydration properties, but with different trends. Swelling showed a progressive decrease with increasing the hydrocolloid concentration; water holding capacity (WHC) only showed a significant decrease when the amount of hydrocolloid added was higher than 0.002 grams/gram of gluten, but beyond that concentration no further decrease in WHC was obtained. Concerning water binding capacity (WBC) a significant decrease was observed when HPMC was added at levels higher than 0.002 g HPMC/g gluten, but the trend was reversed at the highest level tested (0.013 g HPMC/g gluten). Previous studies adding HPMC to gluten showed a steady increase of the water binding capacity ([Rosell and Foegeding, 2007](#)), which agrees with the tendency observed in the present study. Likely, there is an initial interaction between this hydrocolloid and gluten proteins that decrease the interaction with the water molecules, but when increasing the level of the hydrocolloid it acquires a predominant role binding water molecules.

The addition of pectin also induced a significant decrease in the swelling and WHC of the gluten, and an increase of the WBC, and those effects were non-dependent on the level of hydrocolloid added. The presence of ionized carboxyl groups in the pectin structure could be responsible of that behaviour, since they would allow the formation of hydrogen bonds besides stronger interactions like ion-dipole. The formation of electrostatic complexes between anionic hydrocolloids, like pectin, and the gluten proteins has been previously suggested ([Ribotta et al., 2005](#)).

Parameters related to gluten quantity (wet gluten, dry gluten) and quality (gluten index) are summarized in Table 2. Hydrocolloids tested affected in different extent to gluten characteristics. The HPMC did not significantly ($P<0.05$) modify those parameters, whereas arabic gum at the highest ratio tested significantly ($P<0.05$) decreased them and

the addition of increasing levels of pectin induced a steady reduction of those values, suggesting a weakening effect on the gluten structure. The gluten network is mainly formed by the interaction between gliadins and glutenins through numerous hydrogen and disulphide bonds, besides other hydrophobic linkages intra and intermolecular. The electric charge of the pectin increases the possible interaction with gluten proteins, interfering with the formation of the gluten network (Ribotta et al., 2005). Considering the important role of gluten in breadmaking process involving fermentations, only hydrocolloids that do not affect gluten index would be advisable.

The statistical analysis to determine the significance of the single or binary combinations (Table 3) revealed that hydrocolloids nature had a significant ($P < 0.001$) effect on the evaluated properties, and also their concentration affected significantly ($P < 0.001$) all the parameters regardless water binding capacity. The interaction hydrocolloid-concentration induced significant effect on gluten index ($P < 0.01$), swelling and water holding capacity ($P < 0.001$). Therefore, hydrocolloid type is the crucial factor for affecting hydration properties and gluten characteristics, having the concentration a secondary role.

3.2 Gluten protein extractability in the presence of different hydrocolloids

The effect of different hydrocolloids on the protein extractability of gluten balls in SDS solution is depicted in Figure 1. The protein extractability was substantially reduced at 85°C compared with the values obtained at 25°C, which agrees with the effect of heating previously reported (Hayta and Schofield, 2005; Rosell and Foegeding, 2007). According to Pomeranz (1988), the protein extractability in SDS is mainly dependent on its molecular weight. Therefore the lower values obtained at 85°C might be due to the

formation of protein complexes of high molecular weight induced by heating, as pointed out [Rosell and Foegeding \(2007\)](#). Regarding the effect of the hydrocolloids observed at 25°C, no clear tendency was observed with the different hydrocolloids, neither with the different levels tested. [Rosell and Foegeding \(2007\)](#) observed an increase in the protein extractability in the presence of HPMC. The same effect was reported by [Ribotta et al. \(2005\)](#) when added sodium alginate, pectin, xanthan gum or diverse carrageenan to hydrated gluten, due to the formation of soluble complexes derived from anionic hydrocolloids and gluten interaction. Presumably, divergences are consequence of the different hydrocolloid levels used, being the amount of hydrocolloid added in the present study ten times lower than in the reported studies.

3.3 Effect of hydrocolloids on the gluten viscoelastic properties

Viscoelastic moduli values were within the range previously reported for gluten ([Rosell and Foegeding, 2007](#)). At the different temperatures studied, gluten and hydrocolloid-gluten mixtures showed higher elastic modulus (G') than viscous modulus (G'') (Table 4), thus behaved as elastic solids, which agrees with previous reported findings ([Khatkar et al., 1995](#); [Hayta and Schofield, 2005](#)), confirming that gluten and gluten-hydrocolloid mixtures are viscoelastic materials, which exhibit intermediate rheological behaviour between a viscous liquid and elastic solid.

The addition of 0.002 g hydrocolloids per gram of gluten decreased the elastic modulus (G') at 25°C, however further increase of the concentration of arabic gum or pectin (up to 0.013 gram of hydrocolloid per gram of gluten) augmented it, whereas HPMC did not modify this parameter (Table 4). When heating at 85°C, the hydrocolloids induced a decrease of G' at all the concentrations tested, and also during cooling at 25°C, with the exception of arabic gum when added at the maximum level studied. The viscous

modulus (G'') at 25°C showed a decrease when hydrocolloids were added, excepting the increase observed when pectin was added at the highest level (0.013 g pectin/ g gluten) or 0.007 grams of arabic gum per gram of gluten was present, which did not modify the viscous modulus. Similarly, when heating up to 85°C and then cooling till 25°C, the presence of hydrocolloids resulted in a reduction of G'' .

The loss tangent ($\tan \delta = G''/G'$) was calculated to compare the relative changes between the control gluten and the mixtures. The $\tan \delta$ values for all samples were lower than 1. Similar observations on dynamic rheological studies have been reported previously for wheat flour doughs (Dobraszczyk and Morgenstern, 2003). Very small differences were observed in this parameter, indicating rather stable contribution of the elastic and viscous components to the rheological behaviour of the mixtures. Only at 25°C it was observed that HPMC and Arabic gum induced a progressive decrease in $\tan \delta$ value when increasing hydrocolloid level, indicating an increasing contribution of the elastic component in doughs with higher amount of hydrocolloids. The same effect has been observed when hydrocolloids were added to gluten free doughs (Lazaridou et al., 2007).

When the mechanical spectra obtained at different temperatures were compared, it was observed an increase of the absolute value of the elastic modulus after heating up to 85°C and also after cooling again till 25°C (Figure 2), which has been attributed to thermal transitions that increase the protein crosslinking and subsequently the formation of higher molecular weight products (Kokini et al., 1994; Rosell and Foegeding, 2007). The frequency dependence of G' was higher at 25°C than at 85°C, and after cooling the gluten mechanical spectra showed a small frequency dependence of G' , probably due to higher elasticity conferred by protein crosslinking and aggregation process (Hayta and Schofield, 2004; Hayta and Schofield, 2005). At 85°C, the G' trace

showed a biphasic behaviour, with a substantial G' increase until 0.1 Hz, followed by an asymptotic trend, likely heat transmission through protein network generated the initial increase. Concerning the effect of the hydrocolloids, at 25°C only the mechanical spectrum of gluten at very low frequencies was modified (Figure 2). Conversely, the presence of hydrocolloids in hydrated gluten induced a decrease of the absolute G' values at 85°C and the effect was even greater after cooling at 25°C. The HPMC was the hydrocolloid that promoted the highest G' reduction compared to the effect induced by the other hydrocolloids.

Regarding the behaviour of the viscous modulus (G'') against frequency (Figure 3), it was observed higher frequency dependence than the one obtained with G' . Mechanical spectra showed exponential trends at 25°C in the unheated and heated samples, whereas at 85°C mechanical spectra adopted a bell-shape, reaching a minimum at 0.15Hz of frequency. The hydrocolloids barely affected the viscous modulus dependence of frequency, but their effect was readily evident at 85°C and at 25°C after heating-cooling treatment. At those temperatures hydrocolloids reduced the viscous modulus of gluten. The presence of HPMC induced the highest reduction in the G'' of gluten, whereas the effect of arabic gum and pectin was comparable.

Results suggested that hydrocolloids are interfering with the formation of gluten linkages, affecting in different extent to the elastic and viscous moduli. Taking into account that glutenins, protein fraction of gluten, have been associated to the elastic behaviour of gluten, and gliadins confer viscosity (Kokini et al., 1994; Khatkar et al., 1995), these results suggested that the hydrocolloid tested in this study acted predominantly on the gliadin fraction. Among the hydrocolloids tested, the HPMC

yielded the lowest values of gluten viscoelastic moduli, promoting a weakening effect on gluten (Rosell and Foegeding, 2007), which although initially it would not be desirable for breadmaking process, its similar effect on the elastic and viscous components allows obtaining stable loss tangent. In fact, practical experience revealed that HPMC was a good option as breadmaking improver (Bárcenas et al., 2004).

3.4 Effect of different hydrocolloids on viscometric properties of wheat starch

The viscometric properties of wheat starch– hydrocolloid mixture suspensions are showed in Table 5. Generally, the highest hydrocolloid level significantly ($P<0.05$) affected the viscometric parameters of wheat starch. The arabic gum induced the highest effect on the viscosity profile of starch, which at 0.007 and 0.013 g/g of starch significantly reduced the peak viscosity, final viscosity, viscosity at the end of the 95°C holding period, and viscosity at 50° C; moreover, at 0.013 also decreased the breakdown. Pectin at the highest level tested increased peak viscosity, breakdown, final viscosity, viscosity at the end of the 95° C holding period and viscosity at 50°C. The presence of HPMC hardly affected the viscometric parameters, only the final viscosity and the total setback increased when added at the highest level. An increase in viscosities (peak, breakdown, final viscosity) has been previously reported for guar gum and locust bean gum, and assigned to the forces exerted by thickening gums on the starch granules (Huang, 2008). Hydrocolloids immobilize water molecules, resulting in an increase of the effective starch concentration (Yoshimura et al., 1996). However, numerous studies have described the effect of different hydrocolloids on starch gelatinization and retrogradation (Rojas et al., 1999; Rosell et al., 2001), showing the unpredictable behaviour of hydrocolloids, which is highly dependent on their structure, environment conditions and concentration. This picture is even more complicated when mixtures of

hydrocolloids are used in bakery, where synergistic or antagonistic effects can take place. In fact, it has been described that the individual addition of cellulose derivatives, mainly carboxymethyl cellulose, promotes a deleterious effect on dough viscosity, but the binary mixture of carboxymethyl cellulose and HPMC significantly improves dough rheology during cooling (Collar, 2003). Besides, Chaisawang and Suphantharika (2006) reported an increase of peak viscosity, breakdown and final viscosity when guar gum or xanthan gum were added to native tapioca starch; in contrast, the setback augmented in the presence of guar gum, but xanthan gum promoted the opposite effect.

It has been previously reported that the viscometric properties of wheat starch are associated to bread staling during storage, particularly peak viscosity, pasting temperature and viscosity at 95° C, which have been negatively correlated with bread firming kinetics during storage (Collar, 2003). Although the peak viscosity was significantly affected by arabic gum presence (0.007 g/g starch and 0.013g /g starch) and pectin (0.013 g/ g starch), the pasting temperature and viscosity at 95° C were not significantly modified by the presence of hydrocolloids. Overall, the effect of these hydrocolloids on the starch properties suggested that only HPMC and pectin meet the advisable viscometric trend to delay bread staling.

4. Conclusions

Hydrocolloids are able to modify gluten and starch properties, mainly affecting the hydration properties of gluten and also interfering in the gelatinization and retrogradation processes of starch. The extent of the effect was dependent on the hydrocolloid tested and also its concentration. Pectin mainly affected gluten hydration, modifying its quantity and quality. All the hydrocolloid tested, with the exception of

arabic gum, decreased the viscoelastic moduli during heating and cooling, yielding a weakening effect on gluten. In addition, arabic gum acted primarily on the viscometric properties of starch. Therefore, hydrocolloid effect is greatly dependent on the hydrocolloid type, which interacts different with other components of the system.

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Table 1. Hydration properties of hydrated vital gluten in the presence of hydrocolloids

Sample	Hydrocolloid level (g/g gluten)	Swelling (mL/g)	Water holding capacity (g water /g solid)	Water binding capacity (g water/g solid)
Control	0.000	4.16 e	3.34 b	1.53 cde
HPMC	0.002	4.24 e	3.24 b	1.52 bcd
	0.007	3.88 b	2.99 a	1.44 a
	0.013	3.63 a	2.98 a	1.47 ab
Arabic gum	0.002	4.15 de	3.35 b	1.56 de
	0.007	4.10 cde	3.26 b	1.58 ef
	0.013	4.20 e	3.28 b	1.49 abc
Pectin	0.002	3.96 bcd	2.99 a	1.63 fg
	0.007	3.78 ab	2.96 a	1.64 g
	0.013	3.90 bc	2.93 a	1.63 fg

Values are the mean of three replicates

HPMC: hydroxypropylmethylcellulose

Means within columns followed by the same letter were not significantly different (P<0.05)

Table 2. Gluten index, wet gluten and dry gluten of hydrated vital gluten in the presence of hydrocolloids

Sample	Hydrocolloid level (g/ g gluten)	Gluten index (%)	Dry gluten (g/g gluten ball)	Wet gluten (g/g gluten ball)
Control	0.000	96.6 d	0.325 d	0.89 cd
HPMC	0.002	96.0 cd	0.325 d	0.89 d
	0.007	94.7 cd	0.314 bcd	0.86 bcd
	0.013	93.9 bcd	0.316 bcd	0.87 bcd
Arabic gum	0.002	93.9 bcd	0.309 abc	0.87 bcd
	0.007	94.5 cd	0.321 cd	0.90 d
	0.013	90.5 b	0.295 a	0.84 ab
Pectin	0.002	92.6 bc	0.300 ab	0.85 ab
	0.007	93.0 bcd	0.305 ab	0.86 bc
	0.013	84.2 a	0.296 a	0.82 a

Values are the mean of three replicates

HPMC: hydroxypropylmethylcellulose

Means within columns followed by the same letter were not significantly different ($P < 0.05$)

Table 3. Significant single effects and binary interaction of the hydrocolloid type and hydrocolloid concentration on the gluten hydration properties and quantity and quality gluten parameters

Main effect	Swelling	WHC	WBC	Gluten index	Wet gluten	Dry gluten
Hydrocolloid type	***	***	***	***	***	***
Hydrocolloid concentration	***	***	ns	***	***	***
Hydrocolloid x concentration	***	***	ns	**	ns	ns

ns: no significant effect; *significant effect at $P < 0.05$; **significant effect at $P < 0.01$; ***significant effect at $P < 0.001$

WHC: water holding capacity; WBC: water binding capacity

471 **Table. 4** Storage modulus (G') and loss modulus (G'') values of dough made from gluten and hydrocolloids.

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Sample	Hydrocolloid level (g/g gluten)	25°C			85°C			25°C		
		G' (Pa)	G'' (Pa)	$\tan\delta$	G' (Pa)	G'' (Pa)	$\tan\delta$	G' (Pa)	G'' (Pa)	$\tan\delta$
Control	0.0	1623	705	0.43	4712	330	0.07	13880	3246	0.23
HPMC	0.002	1431	592	0.41	3817	256	0.07	10270	2128	0.21
	0.007	1630	642	0.39	3887	258	0.07	9625	1818	0.19
	0.013	1610	599	0.37	3330	284	0.09	8795	1936	0.22
Arabic Gum	0.002	1494	646	0.43	4254	299	0.07	10960	2207	0.20
	0.007	1723	707	0.41	4217	272	0.06	11610	2293	0.20
	0.013	1743	695	0.40	4201	267	0.06	14050	2457	0.17
Pectin	0.002	1419	623	0.44	3582	239	0.07	9967	1979	0.20
	0.007	1651	690	0.42	4078	269	0.07	11550	2415	0.21
	0.013	1709	740	0.43	3789	299	0.08	13280	2511	0.19

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474 HPMC: hydroxypropylmethylcellulose

475 Frequency: 1 Hz.

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Table 5. Effect of hydrocolloids addition on RVA parameters of wheat starch

Parameter	Hydrocolloid	Hydrocolloid (g/g starch)			
		0	0.002	0.007	0.013
Pasting Temp	HPMC		85.9 ab	86.8 ab	86.7 ab
	Arabic gum	86.3 ab	85.2 a	86.8 ab	87.6 b
	Pectin		86.0 ab	86.9 ab	85.6 ab
Peak viscosity	HPMC		2758 c	2796 cd	2788 cd
	Arabic gum	2796 cd	2744 c	2619 b	2501 a
	Pectin		2729 c	2835 d	2989 e
Breakdown	HPMC		496 cde	458 bcd	531 de
	Arabic gum	463 bcd	458 bcd	411 b	332 a
	Pectin		419 ab	444 ab	559 e
Final Visc	HPMC		3203 de	3236 de	3375 f
	Arabic gum	3172 cde	3146 bc	3041 b	2882 a
	Pectin		3091 ab	3259 e	3369 f
Total Setback	HPMC		941 c	897 bc	1117 d
	Arabic gum	838 abc	860 abc	833 abc	713 a
	Pectin		781 ab	869 bc	939 c
Visc at 95	HPMC		232 ab	217 ab	260 b
	Arabic gum	227 ab	244 ab	245 ab	213 a
	Pectin		217 ab	230 ab	228 ab
Visc at end 95	HPMC		2657 bc	2750 cd	2654 bc
	Arabic gum	2718 bcd	2641 b	2528 a	2466 a
	Pectin		2668 bc	2795 d	2934 e
Visc at 50	HPMC		2650 cd	2672 cde	2707 de
	Arabic gum	2656 cd	2629 c	2538 b	2443 a
	Pectin		2607 c	2724 e	2863 f

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HPMC: hydroxypropylmethylcellulose

Means followed by different letters within each parameter are significantly different (P<0.05) (n=3).

FIGURE CAPTIONS

Figure 1. Extractability of proteins from samples at 25°C and heated at 85° C gluten in the presence of different hydrocolloids. Extraction conditions are detailed in material and methods section. Error bars indicate the standard deviation of at least three replicates.

Figure 2. Mechanical spectrum of gluten in the presence of different hydrocolloids (0.007 g of hydrocolloid per gram of gluten) and at different temperatures (25 °C: circles, 85 °C: triangles, and 25 °C* after heating-cooling: squares). Data are at 4×10^{-3} strain and the average of three replications. Storage or elastic modulus (G').

Figure 3. Mechanical spectrum of gluten in the presence of different hydrocolloids (0.007 g of hydrocolloid per gram of gluten) and at different temperatures (25 °C: circles, 85 °C: triangles, and 25 °C* after heating-cooling: squares). Data are at 4×10^{-3} strain and the average of three replications. Loss or viscous modulus (G'').

Figure 1

501 **Figure 2**
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Figure 3