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Original article

Effect of hydrocolloids on gluten-free batter properties and bread quality

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Summary The objectives of this study were to assess the effect of the addition of different hydrocolloids on gluten-free batter properties and bread quality and to obtain information about the relationship between dough consistency and bread quality. Breads were made of rice, corn and soy flours and 158% water. Following hydrocolloids were added: carrageenan (C), alginate (Al), xanthan gum (XG), carboxymethylcellulose (CMC) and gelatine (Gel). Batter consistency, bread specific volume (SV), crumb analysis, crust colour, crumb hardness and staling rate were determined. Hydrocolloids increased batter consistencies: the highest value was obtained with XG, which doubled that of control batter, followed by CMC. Breads with hydrocolloid presented higher SV than control, especially with XG whose SV was 18.3% higher than that of control bread. A positive correlation was found between SV and batter consistency ($r = 0.94$; $P < 0.05$). Crumbs with Gel, XG and CMC presented higher cell average size. XG and CMC crumbs looked spongier. Breads containing hydrocolloid evidenced lighter crusts. Crumb firmness was decreased by XG and CMC addition, and staling rate was slower. Overall, XG was the hydrocolloid that most improved gluten-free bread quality. These results show that, in formulations with high water content, batter consistency is strongly associated with bread volume.

Keywords Batter consistency, bread quality, gluten-free bread, hydrocolloid.

Introduction

Coeliac disease is a chronic enteropathy characterised by an inflammation of the small-intestinal mucosa that results from a genetically based immunological intolerance to gluten (Murray, 1999). The gliadins of wheat gluten contain protein sequences toxic to persons with coeliac disease (Kagnoff *et al.*, 1982), whereas other authors have also shown that wheat glutenins contain toxic sequences (van de Wal *et al.*, 1999). The general prevalence of CD is estimated to be 1 in 300 (Collin *et al.*, 1997), although recent population-based screening studies suggest that the prevalence may be even higher (1 in 100) (Mustalahti *et al.*, 2002).

The inadequate immunological response to gluten proteins may lead to villous atrophy, which causes nutrient malabsorption. General symptoms include diarrhoea, weight loss and fatigue. The only therapy for coeliac patients relies on a lifelong gluten-free diet (Ciclitira *et al.*, 2005).

Gluten-free breads, which lack a gluten matrix, are of poor technological quality, showing low specific volume (SV), high crumb hardness and a high staling rate. Different non-gluten proteins have been included in gluten-free bread formulations to provide structure and gas-retaining properties to the dough and to improve their nutritional quality (Kim & De Ruiter, 1968; Defloor *et al.*, 1993; Toufeili *et al.*, 1994; Sánchez *et al.*, 2002, 2004; Ribotta *et al.*, 2004; Sciarini *et al.*, 2010). Sciarini *et al.* (2010), working with gluten-free breads, showed that, when 10% and 20% of soy flour were added, batter consistency increased two and four times respectively, when compared to batters made only of rice flour. A similar trend was observed for batters made of corn flour. Moore *et al.* (2004) reported a higher consistency of batter with high protein content in gluten-free formulations. This increased batter consistency led to breads with higher SV. However, it has been proposed recently that a lower consistency might favour batter expansion (Renzetti & Arendt, 2009).

To improve the quality of wheatless bread, different kinds of additives have been used, particularly hydrocolloids. These compounds, commonly named gums, are

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capable of controlling both the rheology and texture of aqueous systems throughout the stabilisation of emulsions, suspensions and foams. Various gluten-free formulations include hydrocolloids to mimic the viscoelastic properties of gluten. They comprise a number of water-soluble polysaccharides and proteins with varied chemical structures providing a range of functional properties that make them suitable for this application (Anton & Artfield, 2007).

Thus, the objectives of this work were to assess the effect of different hydrocolloids addition on batter properties and gluten-free bread quality and to obtain information about the relationship between dough consistency and bread quality.

Materials and methods

Materials

Rice flour was supplied by Nora's Skills (8.11% protein, 0.23% ash, 0.8% lipid, 0.25% crude fibre and 90.61% carbohydrates, dry basis; Buenos Aires, Argentina), corn flour was provided by ARCOR (Arroyito, Argentina; 6.87% protein, 0.49% ash, 6.26% lipid, 0.22% crude fibre and 86.14% carbohydrates, dry basis) and inactive, micronised and defatted soy flour was provided by CPA (Hernando, Argentina; 54.97% protein, 7.09% ash, 5.62% lipid, 1.77% crude fibre and 30.61% carbohydrates, dry basis). Standard recipe formulation included shortening (82% total fat, 35% saturated fat, 22% monounsaturated fat and 25% polyunsaturated fat; Dánica, Llavallol, Argentina), salt and compressed yeast (Dánica).The best basic bread formulation was chosen from a pool of previous assays (Sciarini *et al.*, 2010). It was made of 40% rice flour, 40% corn flour, 20% soy flour, 2% salt, 2% shortening, 3% compressed yeast and 158% water (flour basis). Five different hydrocolloids (0.5%) were used: xanthan gum (XG), gelatine (Gel), carrageenan (C) and alginate (Al) were purchased from Saporiti S.A. (Buenos Aires, Argentina), and carboxymethylcellulose (CMC) was supplied by Latinoquímica Amtex S.A. (Buenos Aires, Argentina).

Batter analysis

For the extrusion test, batters were prepared as described for breadmaking but without yeast addition. Batter consistency was determined by the compression–extrusion test, using a Texture Analyser (TA-XT2i; Stable Micro Systems, Surrey, UK) equipped with 25-kg load cell and the forward extrusion cell (A/BE). A constant volume of sample was poured into the extrusion vessel, and the air pockets were removed with a spoon. The extrusion force was measured at a test speed of 1.0 mm s^{-1} to a distance of 25 mm. The force measured at the beginning of batter extrusion was used as an indicator of batter consistency (Texture Expert Version 1.22, 1999).

Breadmaking

Solid ingredients, i.e. flour, salt and eventually hydrocolloids, were manually mixed. Then, predispersed yeast, shortening and water were added and mixed for 3 min at speed 2 (214 r.p.m) in a planetary mixer (Arno Planetaria mixer, Sao Paulo, Brazil). Seventy five grams of the resultant batter was poured into individual aluminium cups, fermented for 60 min in a cabinet at 30 °C with 85% humidity and baked in a rotational gas oven (Ciclo Ingeniería, Buenos Aires, Argentina) at 200 °C for 40 min.

Bread analyses

Specific bread volume

Loaves were weighed 2 h after baking, bread volume (cm^3) was determined by rapeseed displacement method and specific bread volume (cm^3 g^{-1}) was calculated according to the AACC-approved method 72-10 (AACC, 2000).

Crumb image analysis

Digital pictures were taken from slices of 15 mm thickness (2048 × 1536 pixels). Images were analysed using ImageJ Software (1.41o). Cell average area (mm^2) and number of cell mm^{-2} were determined (0.15 and 10.00 mm^2 were the lower and upper area limit values, respectively, for being considered as cells by software). The ratio of small cells ($0.15 < \times < 2.00$ mm^2) to large cells ($2.00 < \times < 10.00$ mm^2) was calculated.

Crust colour

Crust colour was determined with a Minolta Spectrophotometer CM-500d series (Osaka, Japan). L*, a* and b* values were obtained.

Crumb texture

Crumb firmness analysis was conducted according to the AACC-approved method 74-09 (AACC, 2000). Bread was longitudinally sliced using a slice regulator to obtain pieces of 15 mm thickness. Two bread slices were taken from the centre of each loaf and were used to evaluate crumb texture. Texture profile analysis (TPA) was carried out using a TA-TX2i Texture Analyser (Stable Micro Systems) equipped with the 25- kg load cell and a 25- mm cylindrical probe. TPA was carried out on loaves 2 h after baking (day 0) and at days 1 (24 h) and 3 (72 h). The test was performed at a speed of 5.0 mm s^{-1} to compress the bread crumb to 40% of its original height. The staling rate was calculated by linear regression analysis between firmness values of 0, 1 and

3 days. The slope obtained from the firmness–time curve was used as an indicator of staling rate.

Statistical analysis

All measurements were taken in triplicates. Data were analysed using analysis of variance and the test of Fisher's least significant difference at a significance level of 0.05. A correlation test was conducted to evaluate the relationship among variables ($P < 0.05$). These tests were carried out with Infostat software (2004).

Results and discussion

Batter analysis

Figure 1 shows the typical extrusion–compression curve of these batters, where it is shown that the force needed to begin extrusion is considered as batter consistency (Fig. 1a). It also presents the extrusion curves for control sample and batters with CMC and XG addition, which were the hydrocolloids that most enhanced batter consistency (Fig. 1b). Table 1 presents consistency values for all samples. As shown, all batters with added hydrocolloids had higher consistencies compared to control. Escudier *et al.,* (2001), working with CMC and XG solutions at room temperature, found that XG solutions presented higher viscometric viscosities (Pa.s) than CMC solutions. Consistently, in this work, the highest consistency was obtained by adding XG, followed by batters with CMC.

XG may form a extremely stiff intramolecular double-stranded helical conformation (Sato *et al*., 1984; Bezemer *et al*., 1993). The high molecular weight molecules of XG form complex aggregates through hydrogen bonds and polymer entanglements, resulting in a high Newtonian viscosity at low shear rates.

Besides, batters with carrageenan, alginate and gelatine showed the lowest consistencies among samples with hydrocolloid incorporation. XG and CMC are molecules known to be soluble in cold water, while C and Al require hot water for complete hydration (Anton & Artfield, 2007). This fact could explain the differences observed in batter behaviour. Gelatine, although soluble in cold water, requires higher temperatures (65 °C) to exert its thickening effect.

Bread quality

Specific bread volume

As shown in Fig. 2, all hydrocolloids had a positive effect on gluten-free bread SV. The improving effect of hydrocolloids on bread volume has been reported by several authors (Haque & Morris, 1994; Gujral & Rosell, 2004; Bárcenas & Rosell, 2005; McCarthy *et al*., 2005). XG addition resulted in the bread with highest

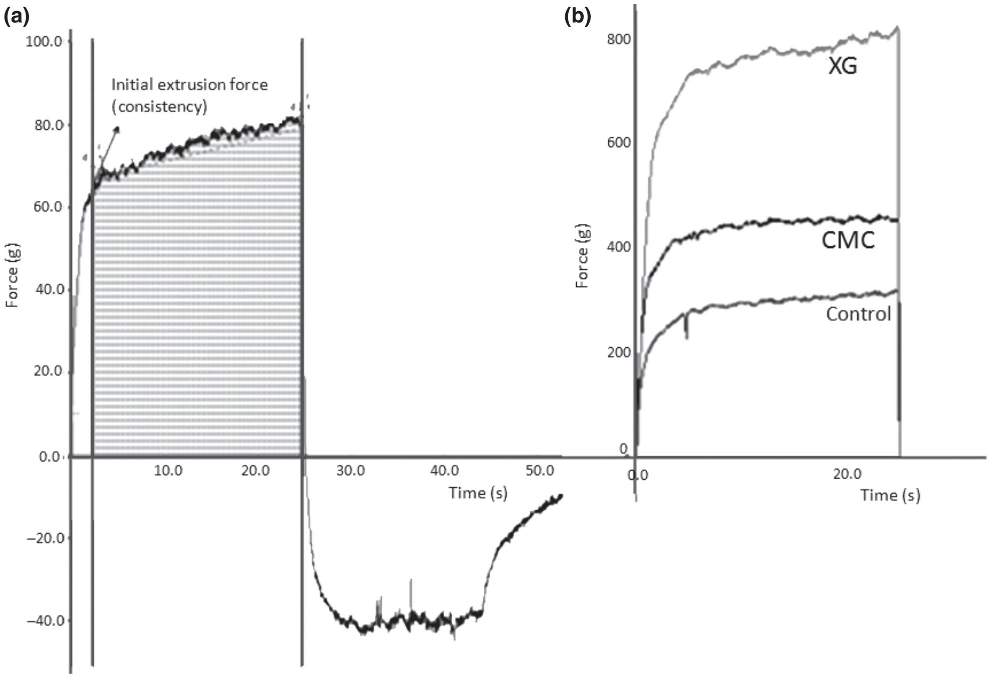

Figure 1 (a) Typical extrusion–compression force for gluten-free batter; (b) extrusion–compression curve for control batter and batters with carboxymethylcellulose and xanthan gum incorporation.

Table 1 Batter consistency (g) for studied gluten-free batters

Sample	Batter consistency
Control	285.4 ± 6.7^{a*}
C	335.8 ± 27.2^{b}
Al	358.3 ± 3.9^{b}
XG	678.9 ± 3.6^{d}
CMC	419.5 ± 13.1^{c}
Gel	347.0 ± 11.3^{b}

C, carrageenan; Al, alginate; XG, xanthan gum; CMC, carboxymethylcellulose; Gel, gelatine.

*Values followed by different letters are significantly different ($P < 0.05$).

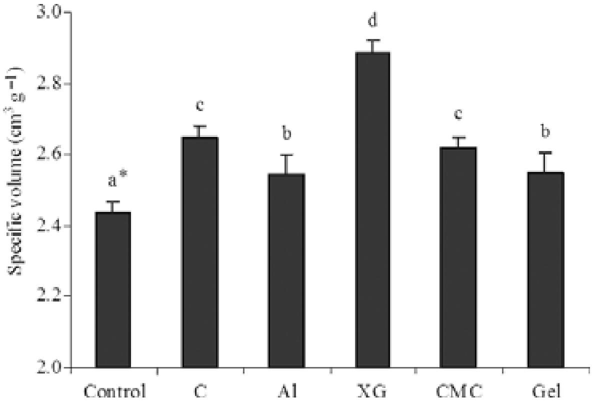

Figure 2 Specific volume (cm^3 g^{-1}) for gluten-free control bread and breads with hydrocolloid addition (C, carrageenan; Al, alginate; XG, xanthan gum; CMC, carboxymethylcellulose; and Gel, gelatine). *Bars with different letters are significantly different ($P < 0.05$).

SV, followed by CMC and C, while Al and Gel resulted in the lowest SV considering hydrocolloid-added samples. These results are in agreement with other authors who, adding several hydrocolloids to gluten-free breads (xanthan, guar gum, locust bean gum and traganth), found that the highest quality bread was the one containing XG (Acs *et al.*, 1997). Nevertheless, hydrocolloids' effect on specific bread volume is not as clear, being highly dependent on the formulation used, the level of hydrocolloid incorporation and the origin and source of the gum. For example, other authors, such as Lazaridou *et al.* (2007) working with gluten-free breads added with CMC, pectin, agarose, XG and oat β-glucans, found the highest SV for CMC, while XG added at 1% did not improve SV compared to control bread, and it was even decreased when XG was added at 2%. In a similar way, Schober *et al.* (2005) found a negative effect of XG on gluten-free bread SV made of sorghum. Mezaize *et al.* (2009) found no positive effect of CMC or XG on gluten-free breads' SV. However, it is worth highlighting that all these authors worked with higher hydrocolloid levels compared to 0.5% used in this work.

The discussion in the literature has focused on the effect of batter consistency on gluten-free bread SV. While Renzetti & Arendt (2009) have suggested that the decrease in batter consistency may improve batter development owing to a reduced resistance to expansion during proofing, others claimed that higher batter consistency leads to higher SV breads, because an increase in batter viscosity improves dough development and gas retention, thereby increasing loaf volume (Marco & Rosell, 2008; Sciarini *et al.*, 2010). In this work, a positive relationship was found between loaf SV and batter consistency ($r = 0.94$; $P < 0.05$). Summing up, it is quite clear that the relationship between batter properties and bread volume depends on the type and level of hydrocolloids added, the level of water incorporation and the interactions established between hydrocolloid and batter constituents.

Crust colour

In general, a lower L* value indicates a darker crust, a* positive value is associated with crust redness, whereas a higher b* value leads to higher crust yellowness. Table 2 shows that Gel and Al crust lightness were the similar to that of control, and breads with XG and CMC showed a lighter crust. In general, breads with added hydrocolloid evidence lighter crusts (Sharadanant & Khan, 2003; Lazaridou *et al.*, 2007; Mandala *et al.*, 2007; Shittu *et al.*, 2009). This could be attributable to the effect of hydrocolloids on water distribution, which impacts on Maillard reaction and caramelisation. Similar results were obtained by Mezaize *et al.* (2009) working with gluten-free breads. On the other hand, we found a darkening of the crust (lower L* values) with carrageenan addition, in agreement with Mandala *et al.* (2009) who worked with wheat bread. Al, CMC and Gel increased crust yellowness and redness, being Gel the hydrocolloid that most increased a* value.

Crumb structure

Consumers' choice of breads is greatly influenced by crumb structure. Regarding wheat bread, in general, a

Table 2 Crust colour parameters for studied gluten-free breads

	Colour		
Sample	L*	a*	b*
Control	50.6 ± 3.3^{b}	12.5 ± 0.6^{b}	33.3 ± 1.8^{a}
C	44.7 ± 4.4^{a}	12.4 ± 0.9^{ab}	32.2 ± 2.8^{a}
Al	51.6 ± 4.8^{b}	14.0 ± 0.4^{c}	37.8 ± 1.8^{b}
XG	57.4 ± 1.1^{c}	11.6 ± 0.6^{a}	33.5 ± 0.4^{a}
CMC	59.6 ± 0.6^{c}	13.9 ± 0.1^{c}	38.2 ± 0.1^{b}
Gel	53.9 ± 1.5^{bc}	16.9 ± 1.2^{d}	38.5 ± 1.8^{b}

C, carrageenan; Al, alginate; XG, xanthan gum; CMC, carboxymethylcellulose; Gel, gelatine.

*Values followed by different letters are significantly different ($P < 0.05$).

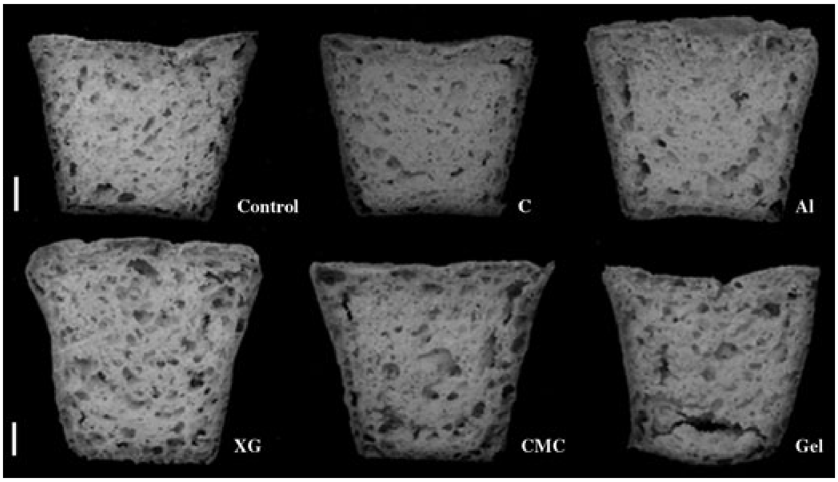

Figure 3 Digital images of gluten-free bread slices (Bar: 1 cm). C, carrageenan; Al, alginate; XG, xanthan gum; CMC, carboxymethylcellulose; Gel, gelatine.

fine crumb structure is preferred. Usually, gluten-free bread shows high cell-wall thickness and a coarse and dense structure resulting from the incapability to incorporate gases during mixing and/or to retain the CO_2 formed during proofing, owing to the lack of a viscoelastic network. From Fig. 3, it can be observed that bread with XG added shows an opener structure than the other samples, and it shows no fractures on its internal structure. CMC bread presents a qualitative good structure, although, when compared to XG, it looks denser, with a greater number of small cells. Bread with C shows a close structure, similar to that of control, whereas bread with Al has several small cells with bigger cells in between. A common finding has been the fracture on the structure of gelatine-added breads owing to a weak crumb structure. All samples, except those with XG and CMC, present a depressed centre area, resulting from a rapid water loss during baking and an associated shrinkage of the structure. XG and CMC may have formed a network, which could enhance crumb structure, thus avoiding this shrinking effect.

Cell (air) total area of breadcrumbs ranged from 20.6 ± 2.3 to 30.3 ± 2.4% showing no significant differences among formulations. As expected, crumbs with higher number of cells mm^{-2} showed smaller cell size (Fig. 4). Lower number of cells mm^{-2} (compared to control bread) obtained for Gel, CMC and XG was associated with higher cell average size, while breads with C and Al had higher values in relation to smaller cell sizes when compared to control. Other authors observed no significant differences in this parameter for XG- and CMC-added bread with regard to control (Mezaize *et al.*, 2009). In this work, XG and CMC incorporation led to more aerated crumbs. These breads showed the lowest small/big cells ratio, indicating that bigger air cells are formed (Fig. 5). The use of some hydrocolloids, such as XG and HPMC, in gluten-free bread has been reported to produce a web-like structure similar to the structure of the standard wheat bread (Ahlborn *et al.*, 2005).

Crumb firmness

Hydrocolloids are added to bakery products for improving their shelf life by keeping the moisture content and retarding the staling (Collar *et al.*, 1999; Gray & BeMiller, 2003; Bárcenas *et al.*, 2004). From

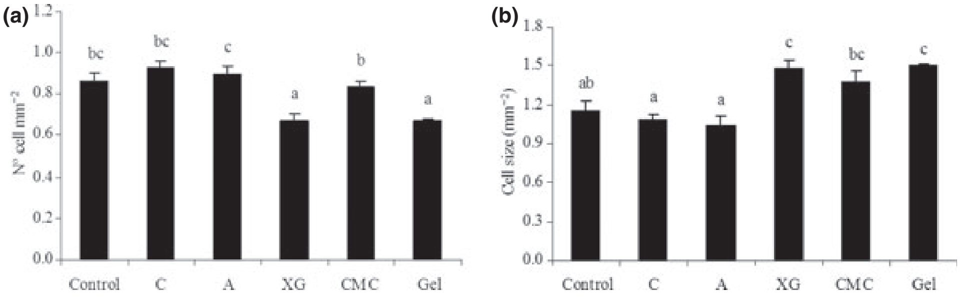

Figure 4 Number of cell mm^{-2} (a) and cell average size (b) for gluten-free control bread and breads with hydrocolloid addition (C, carrageenan; Al, alginate; XG, xanthan gum; CMC, carboxymethylcellulose; and Gel, gelatine). *Bars with different letters are significantly different ($P < 0.05$).

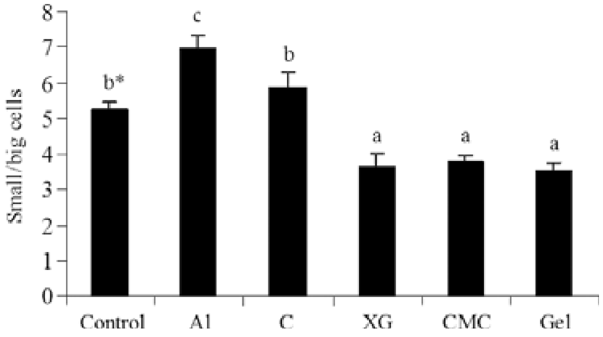

Figure 5 Ratio of small ($0.15 < \times < 2$ mm^2) to big cells ($2.00 < \times < 10$ mm^2) for gluten-free control bread and breads with hydrocolloid addition (C, carrageenan; Al, alginate; XG, xanthan gum; CMC, carboxymethylcellulose; and Gel, gelatine). *Bars with different letters are significantly different ($P < 0.05$).

Table 3 Crumb firmness (g) of gluten-free breads

Sample	Initial firmness (g)	Slope (g day^{-1})
Control	720.4^{c*}	62.2^{ab}
C	818.2^{c}	72.9^{abc}
Al	723.2^{c}	138.6^{c}
XG	402.6^{a}	22.9^{a}
CMC	639.2^{b}	28.8^{a}
Gel	730.8^{c}	128.9^{bc}

C, carrageenan; Al, alginate; XG, xanthan gum; CMC, carboxymethylcellulose; Gel, gelatine.

*Values followed by different letters within a column are significantly different ($P < 0.05$).

Table 3, it is evident that XG was effective in diminishing initial crumb hardness and, to a lesser extent, CMC. Al, C and Gel did not show any difference compared to control bread. Softer crumbs were related to higher SV of breads. Bread initial firmness showed a significant correlation with batter consistency ($r = -0.94$, $P < 0.05$). This could be related, once again, to the highest capacity of more consistent batters to retain CO_2 during proofing, thus diminishing crumb hardness. The slope of the regression straight line obtained by measuring crumb firmness at different storage times (0, 24 and 72 h, 25 °C) indicates that XG and CMC did improve crumb's staling behaviour by decreasing firming rate upon storage at room temperature. Brennan *et al.* (2004) reported that XG stabilised starch gels and reduced starch retrogradation. Davidou *et al.* (1996), working with wheat bread, reported that both the degree of crumb firmness and the rate of staling during storage were reduced by adding hydrocolloids; they proposed that gums modified the organisation of the amorphous phase of crumb, perhaps by inhibiting the development of the macromolecular entanglement. This may also occur in gluten-free breads.

Conclusion

The addition of hydrocolloids increased batter consistency and improved gluten-free bread quality, especially XG, which led to breads with high volume, increased cell average size, and lower crumb firmness and staling rate over storage; similarly, it improved breads' overall appearance. Current results show that, in formulations with high water content, batter consistency is strongly associated with bread volume.

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