Improvement of whole wheat dough and bread qualities with hydrocolloids

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Abstract

Hydrocolloids are used to improve dough handling and bread quality and retard staling. The strengthening effect is particularly beneficial to bread prepared from whole wheat flour and other flours of low gluten quality. The hydrocolloids carboxymethyl cellulose (CMC), guar gum, hydroxypropyl methylcellulose (HPMC), sodium alginate, and xanthan gum were evaluated individually at 0.25, 0.5, and 1.0% flour weight basis (fwb) in whole wheat dough and bread to improve loaf volume and reduce staling. Dough properties were determined by farinograph, mixograph, Chen-Hoseney stickiness test, and Kieffer rig uniaxial extensibility using a texture analyzer. Effect on starch retrogradation in bread crumb was quantified by differential scanning calorimetry (DSC) after 7 days. Hydrocolloids increased water absorption and mixing time for whole wheat dough. All hydrocolloids except for CMC increased specific loaf volume for at least one of the levels tested ($P < 0.01$), with minimal change to crumb structure. HPMC (all levels) and xanthan gum (medium level) produced the greatest increases in specific loaf volume. The high level of guar gum and medium level of HPMC reduced crumb hardness on Day 1 ($P < 0.01$). On Day 7, only HPMC and xanthan gum at the medium level decreased crumb hardness compared to the control. HPMC, sodium alginate, and xanthan gum decreased the rate of crumb firming during storage. No significant changes in amylopectin retrogradation or amylose-lipid complexation were observed, although xanthan gum showed a trend toward decreasing formation of the complex. HPMC is recommended as the most favorable hydrocolloid to increase loaf volume and delay staling of whole wheat bread.

1 Introduction

Hydrocolloids, or gums, are high molecular weight polymers that are hydrophilic and form gels or highly-viscous suspensions in water-based systems. Most are polysaccharides, but the group also includes proteins, such as gelatin (Saha & Bhattacharya, 2010). Hydroxyl groups allow these molecules to interact with and bind water. In foods, hydrocolloids are used to modify texture and viscosity, and can be broadly classified as thickeners or gel formers (Saha & Bhattacharya, 2010). Hydrocolloids come from several sources, including seeds, plant exudates or cell wall material, seaweed, cellulose derivatives, microbial fermentation products, and modified starches (Ferrero, 2017; Saha & Bhattacharya, 2010). Hydrocolloids are used extensively in gluten-free bakery products to provide a certain degree of strength, stability, and viscoelasticity in the absence of a gluten network (Anton & Artfield, 2008). In wheat-based bakery applications, hydrocolloids increase water absorption and modify dough properties, provide stability to frozen dough and par-baked bread, and, in the final product, increase loaf volume, improve crumb texture, increase moisture retention, and retard staling (Ferrero, 2017; Kohajdová

& Karovičová, 2009). The specific results depend on the structure of the hydrocolloid. Whole wheat bread in particular can benefit from the strengthening effects of hydrocolloids, since the bran and germ in whole wheat flour lead to a weaker gluten network and smaller loaf volume compared to white bread. The effects of hydrocolloids in whole wheat dough and bread have been previously reviewed (Tebben et al., 2018), but the literature lacks a comprehensive study of the individual effects of a variety of hydrocolloids on both dough and bread properties. Five hydrocolloids were chosen to represent a range of structures and sources: CMC (carboxymethyl cellulose) and HPMC (hydroxypropyl methylcellulose) (cellulose derivatives), guar gum (galactomannan, from guar beans), sodium alginate (seaweed extract), and xanthan gum (product of bacterial fermentation). The five hydrocolloids were evaluated individually at three levels. The objectives of this research were to determine the specific effects of each hydrocolloid on the physical properties of dough and bread made with whole wheat flour, with the aim of increasing loaf volume and decreasing staling.

2 Materials and methods

2.1 Materials

Whole wheat flour (13.5% moisture content, 13.85% protein) was kindly supplied by Mennel Milling Company (Fostoria, OH, USA). Food grade CMC, guar gum, HPMC (Methocel® F50 Hydroxypropyl Methylcellulose), and sodium alginate were provided by Modernist Pantry (Eliot, ME, USA). Xanthan gum from Xanthomonas campestris was purchased from Sigma-Aldrich (St. Louis, MO, USA). Food grade calcium propionate was obtained from Niacet Corporation (Niagara Falls, NY). Instant yeast (Bellarise Red brand), sucrose (Domino brand), sodium chloride (Morton brand), and shortening (Crisco brand) were obtained from a local supermarket.

2.2 Dough preparation and properties

Each of the five hydrocolloids were evaluated in whole wheat dough at three levels: 0.25, 0.5, and 1.0% (flour weight basis, fwb), with the exception of sodium alginate, which was only evaluated at the low (0.25% fwb) and medium (0.5% fwb) levels, because a suitable dough could not be formed with the high dose (1.0% fwb). A control dough without hydrocolloids was also prepared for all analyses.

2.2.1 Mixograph analyses

Dough mixing properties were determined by a mixograph (National Manufacturing, Lincoln, NE). Flour (10 g, 14.0% moisture basis), water, and hydrocolloid, when tested, were mixed in a 10 g mixograph bowl at 22 °C. The water absorption and mixing time as determined by midline peak time were used to prepare all samples for the remaining dough tests.

2.2.2 Farinograph analyses

Farinograph dough properties were measured with a 50 g DoughLAB (Perten Instruments North America, Springfield, IL), using AACCI Method 54-70.01 and extending the length of the test to 12 min beyond the peak resistance or until the top of the curve fell below 500 farinograph units (FU), whichever was later. The following parameters were determined: water absorption (percentage (fwb) of water required to reach a dough consistency of 500 FU), dough development time (DDT; time for dough to reach peak consistency), stability (time for the top curve to reach peak resistance and to fall below peak resistance), and mixing tolerance index (MTI; the difference in FU from the top of the curve at peak mixing time to the top of the curve five minutes after the peak mixing time).

2.2.3 Chen-Hoseney stickiness test

Dough stickiness was analyzed using a TA-XT Plus Texture Analyzer (Stable Micro Systems, Godalming, Surrey, UK) equipped with a 30 kg load cell. A SMS/Chen-Hoseney Dough Stickiness Rig and 25 mm Perspex cylinder probe were used for the test as described by Huang and Hoseney (1999). Parameters recorded included stickiness (in N), work of adhesion (in N.s), and cohesiveness (in mm). Six replicates were performed for each dough, and each dough was tested in duplicate.

2.2.4 Kieffer rig uniaxial extensibility

Uniaxial extensibility was measured using the Kieffer dough and gluten extensibility rig on the TA-XT Plus Texture Analyzer. Approximately 10 g of prepared dough was pressed in the lubricated Teflon molder and allowed to rest at 22 °C for 30 min. A strip of dough was removed from the molder and clamped between the plates of the Kieffer rig before each test. A test speed of 3.3 mm/sec and trigger force of 0.049 N were used. Resistance to extension (Rmax, in N) and extensibility (ERmax, in mm) were recorded as the peak force and the distance at the peak force, respectively. Nine strips per dough were tested, and each dough treatment was prepared in duplicate.

2.3 Bread making

Bread was prepared following the 100 g flour straight-dough bread-making method (AACC International 10-10.03). Dough was mixed in a 100 g bowl pin mixer (National Manufacturing, Lincoln, NE, USA), and bread was baked in a reel oven (National Manufacturing Co, Lincoln, NE, USA). Slight modification of the AACC method included addition of 0.3 g calcium propionate to prevent mold growth and use of 2 g instant yeast instead of active dry yeast. Water and mixing times were based on mixograph analysis and optimized through preliminary baking trials. Hydrocolloids were added to the formulation according to the experimental design at 0.25, 0.5, and 1.0% (fwb), again with the exception of sodium alginate, which was only added at the low and medium levels. Bread loaf volume was determined by rapeseed displacement (AACC International 10-05.01), and weight was measured immediately after baking. Loaf height was recorded by a standard proof height gauge (The Bates MFG. CO., Hackettstown, NJ, USA). Upon cooling, bread was transferred to polyethylene Zip-lock bags and properly sealed. The following day, bread was sliced into 15 mm thick slices for further analysis. Three replicates of each treatment were prepared over three separate days of baking.

2.3.1 Evaluation of crumb structure

The central slice of each loaf was photographed using a C-Cell Bread Imaging System (Calibre Control International Ltd., Appleton, Warrington, UK). Each image was analyzed by the provided software to quantify the number of cells, cell wall thickness, and cell diameter. The analyses were conducted in triplicate.

2.3.2 Texture properties

Crumb texture was analyzed according to Tebben et al. (2020). Texture properties analysis (TPA) was performed after storage for 1, 3, and 7 d under ambient conditions (22 °C) to determine the effect of hydrocolloids on changes to crumb texture. To evaluate the influence of hydrocolloids on bread firming, linear regression was used to determine the slope of the increase in crumb hardness during storage. Loaves were prepared in triplicate. Two of the central slices from each loaf were analyzed.

2.3.3 Moisture content

Following TPA, a sample of the crumb (~1 g) from each slice was weighed and then dried at 105 °C for 3 h in a convection oven. Samples were allowed to cool for 45 min in a desiccator before weighing. Moisture content was determined for bread after storage for 1, 3, and 7 d. Loaves were prepared in triplicate. Two central slices from each loaf were analyzed for moisture content.

2.3.4 Retrogradation

Thermal phase transitions of bread stored for 7 d at ambient temperature (22 °C) were measured using a Q200 differential scanning calorimeter (DSC) (TA Instruments, New Castle, DE) according to Tebben and Li (2019). The onset temperature (To), peak temperature (Tp), and melting enthalpy (ΔH, joules/g) were determined for the melting of retrograded amylopectin (~ 60 °C) and the amylose-lipid complex (115-120 °C). Two replicates were performed for each treatment.

2.4 Statistical analysis

Treatment means were compared to the control using Dunnett's test in SAS Studio 3.7 (SAS Institute Inc., Cary, NC). Simple linear regression analysis of bread firming was also conducted using SAS Studio 3.7.

Table 1 Farinograph and mixograph properties of control and hydrocolloid-supplemented whole wheat dough compared to water absorption and mix times used for baking tests

Treatment	Mixograph water absorption (%, fwb)	Mixograph peak time (min)	Midline peak value (%)	Midline peak width (%)	Farinograph water absorption (%, fwb)	Dough development time	Stability (min)	Mixing tolerance index (FU)	Baking water absorption (%, fwb)	Baking mixing time (min)
Control	71	4.67	57.74	31.47	75.6	5.5	8.2	33.7	71	4.42
CMC low	71	4.60	59.86	35.72	78.0	5.6	5.5	53.6	72	4.33
CMC med	71.5	4.97	56.90	25.73	79.7	6.1	5.3	53.6	73	4.50
CMC high	73	6.24	55.03	26.14	82.3	6.4	4.2	67.8	75	5.25
guar low	71	3.96	48.32	25.57	75.8	7.3	7.9	44.9	72	3.83
guar med	71.5	4.39	53.64	28.76	75.8	7.1	8.9	27.5	73	4.25
guar high	73	4.39	56.64	27.48	77.2	7.0	8.4	33.2	75	4.33
HPMC low	71	4.16	55.10	24.76	78.0	5.0	6.5	43.4	72	3.83
HPMC med	71.5	4.32	56.99	31.82	79.7	5.4	6.5	42.8	73	3.67
HPMC high	73	4.25	56.62	30.64	84.5	5.6	5.4	50.0	73	3.50
alginate low	72	5.36	58.56	29.03	77.7	5.4	5.4	55.1	73	4.25
alginate med	73	6.84	53.23	25.12	79.5	5.8	3.9	63.2	75	4.50
xanthan low	72	4.53	54.52	23.32	77.8	6.1	7.2	40.3	72	4.03
xanthan med	74	6.08	48.96	20.03	79.5	6.2	5.5	46.9	76	6.00
xanthan high	76	6.53	44.88	23.85	81.7	9.0	6.2	58.1	76	6.75

Stability: Difference between arrival and departure times (time for top curve to reach peak resistance and to fall below peak resistance)
MTI: The difference in Farinograph Units (FU) from the top of the curve at peak mixing time to the top of the curve five minutes after the peak mixing time.

Sourcec: Li et al 2021 / Graphic: ct 2021

3 Results and discussion

3.1 Dough properties

3.1.1 Mixograph analyses

The mixograph properties for each treatment are shown in Table 1. All hydrocolloids increased the water absorption of the dough, as expected due to their hydrophilic nature and high hydration capacity (Ferrero, 2017). Xanthan gum produced the greatest increase in water absorption. With the exception of HPMC, higher amounts of hydrocolloids and consequently greater amounts of water increased the peak time. That is, the dough took a longer time to develop. Mixograph properties for dough prepared with hydrocolloids have generally not been widely reported in the literature, most likely due to the somewhat subjective nature of the test – the operator must determine the ideal water absorption based on his or her interpretation of the mixograph curve, which is one of the most challenging tasks in mixograph operation (Ohm & Chung, 1999). The water absorption is typically estimated based on protein and moisture content of the flour (AACC International Method 54-40.02; Ohm & Chung, 1999), but adjustments for added ingredients are determined empirically. In tests of only flour and water, mixograph water absorption significantly correlates with baking water absorption (Ohm & Chung, 1999). A comparison of mixograph and baking water absorption and mix times for the hydrocolloids treatments are presented in Table 1. Baking water absorption followed the same trend as mixograph water absorption, but the former was often increased to achieve a better dough and/or higher loaf volume.

The midline peak value and midline peak width are both indicators of dough strength, and have been correlated with loaf volume (Ohm & Chung, 1999). Increasing levels of CMC, alginate, and xanthan gum decreased the midline peak value, whereas guar gum increased midline peak value, and HPMC had little effect on this parameter. However, HPMC did increase the midline peak width, suggesting a modest strengthening effect.

3.1.2 Farinograph analyses

Both the type and amount of hydrocolloid influenced the farinograph parameters (Table 1). Except for the low and medium levels of guar gum, all hydrocolloids increased the farinograph water absorption. Linlaud and colleagues (2009) similarly found that xanthan gum produces a large increase in water absorption, whereas guar gum does not. Rosell and colleagues (2001) also demonstrated that HPMC, alginate, and xanthan gum increased the water absorption in white flour dough. They found that HPMC increased water absorption to the greatest extent, similar to the present work. The degree of increase in water absorption depends on the chemical structure of the hydrocolloid, particularly the number of hydroxyl groups, which interact with water through hydrogen bonds (Rosell et al., 2001).

In accordance with the aforementioned study (Rosell et al., 2001), xanthan gum increased DDT, which is the time for the dough to reach peak resistance, while HPMC did not affect this parameter. Guar gum also increased DDT in the whole wheat dough, as reported for white dough (Linlaud et al., 2009). CMC was shown here to increase DDT, and alginate resulted in only a modest increase, in contrast to the findings of Rosell et al. (2001). The specific type of alginate could explain the differences in our findings compared to published data. Alginates can be

Table 2 Textural properties of control and hydrocolloid-supplemented whole wheat dough

Treatment	Stickiness[a] (N)	Work of adhesion[a] (N.s)	Dough cohesiveness[a] (mm)	R_{max}[b] (N)	E_{Rmax}[b] (mm)
Control	0.329±0.035	0.038±0.014	2.40±0.73	0.171±0.011	27.03±4.52
CMC low	0.345±0.040	0.047±0.018	2.95±0.76	0.173±0.011	32.19±4.35
CMC med	0.330±0.017	0.036±0.009	2.25±0.46*	0.168±0.015	31.53±3.88
CMC high	0.396±0.060*	0.060±0.026	3.01±0.83	0.181±0.017	31.03±2.69
guar low	0.309±0.038	0.028±0.017	1.90±0.72	0.162±0.011	24.17±2.09
guar med	0.323±0.025	0.033±0.008	2.45±0.49	0.164±0.013	24.33±3.32
guar high	0.315±0.044	0.030±0.012	2.14±0.67	0.171±0.013	26.01±2.29
HPMC low	0.333±0.034	0.034±0.015	2.15±0.72	0.177±0.008	25.89±3.00
HPMC med	0.339±0.024	0.033±0.009	1.88±0.41	0.172±0.012	25.47±2.37
HPMC high	0.366±0.028**	0.043±0.011	2.13±0.43	0.173±0.015	28.82±1.93
alginate low	0.301±0.039	0.033±0.012	2.50±0.95	0.176±0.011	26.67±2.80
alginate med	0.308±0.022	0.028±0.005	2.20±0.59	0.178±0.013	26.68±4.33
xanthan low	0.295±0.032	0.030±0.010	2.18±0.75	0.165±0.011	23.12±3.36
xanthan med	0.285±0.025	0.027±0.009	1.87±0.54	0.173±0.014	17.98±2.30***
xanthan high	0.315±0.033	0.032±0.009	1.83±0.45	0.247±0.016***	12.34±0.76***

[a]All means were compared to the control from the same day the treatment was analyzed. Level of significance indicated by * = 0.05 to 0.01, ** = 0.01 to 0.001, and *** = 0.001 and lower.
[a]Stickiness, work of adhesion, and dough cohesiveness as measured by the SMS/Chen-Hoseney dough stickiness test. Means for each treatment are the averages of 12 replicates.
[b]R_{max} (resistance to extension) and E_{Rmax} (extensibility) as measured by Kieffer dough and gluten extensibility test. Means for each treatment are the averages of 18 replicates.

Sourcec: Li et al 2021 / Graphic: ct 2021 derived from several species of algae, which leads to variation among the chemical makeup of the product (Kohajdová & Karovičová, 2009). CMC, HPMC, alginate, and xanthan gum all decreased stability and increased MTI (i.e., the drop in dough consistency five minutes after the peak resistance is reached). Alginate had the most pronounced effect in this regard. Therefore, all of these doughs exhibited a greater breakdown compared to the control dough. In contrast, alginate and xanthan both increased stability and decreased MTI in white dough (Rosell et al., 2001). Another published study found that the hydrocolloids xanthan gum, locust bean gum, and high-methoxyl pectin increased the stability of white dough in the absence of salt, but that the hydrocolloids actually decreased dough stability when 2% NaCl was also added (Linlaud et al., 2009). The authors suggested a negative interaction effect between the salt and hydrocolloids. In a similar way, the hydrocolloids may have a negative interaction effect with ions or other components in the bran and germ, leading to the decreased stability of whole wheat dough.

For guar gum, the medium level increased stability and decreased MTI, indicating a stronger dough that is more tolerant to overmixing, similar to its effect in white dough (Linlaud, N. E. et al., 2009). These beneficial effects were removed at the high level of guar gum, possibly because the higher amount of gum required more water, creating a more viscous or weaker dough.

3.1.3 Dough stickiness

Dough handling properties, including textural attributes such as stickiness, are important to industrial bakery settings. Most of the hydrocolloids did not significantly alter the parameters measured by the Chen-Hoseney stickiness test, namely dough stickiness, work of adhesion, and cohesiveness (Table 2). Tests of xanthan gum and HPMC, at levels up to 0.112 and 0.348 g/100g flour, respectively, also did not find significant effects on dough stickiness (Collar et al., 1999). The present study did find exceptions for the high levels of CMC and HPMC, which increased dough stickiness by ca. 12 and 14%, respectively, compared to the control. Ahmed & Thomas (2018) reported that, in general, neither xanthan gum nor guar gum significantly increased the stickiness of brown wheat flour/β-glucan composite dough, although increases were observed for mid-range levels after holding times of 60 and 90 min. It may be expected that addition of hydrocolloids and the resultant increase in water would increase dough stickiness, but the strong interaction between the water and hydrocolloids appeared to mitigate such an effect by limiting the amount of unbound water. Our results suggest that when the water absorption and mixing time are optimized, a negative influence on dough textural properties can be minimized. This conclusion agrees with the knowledge that for nonsticky dough flour, increasing either the water absorption or the mix time will increase dough stickiness (Chen & Hoseney, 1995). Overmixing breaks down gluten proteins, which may increase stickiness either through a weakening of the gluten network and/or by reducing the water holding capacity of the gluten. Excess water may increase stickiness due to a weakening of the dough or by increasing surface stickiness (Chen & Hoseney, 1995).

3.1.4 Kieffer rig uniaxial extensibility

The Kieffer rig functions as a small scale Brabender extensograph and measures unixial extension, with the advantages of a constant amount of dough being deformed, small scale deformations that are more relevant to the deformations occurring during fermentation, and the measurements of force in Newtons (Dunnewind et al., 2004). Except for xanthan gum, the addition of hydrocolloids did not significantly alter resistance to extension (Rmax) or extensibility (ERmax) of the whole wheat dough (Table 2). Contrary to our findings using the Kieffer rig, Armero and Collar (1996b) reported that CMC and HPMC decreased resistance to extension of whole wheat dough as measured by extensograph. Extensograph measurements on white dough taken after 45 min of resting showed that addition of 0.5% (fwb) alginate, HPMC, and xanthan decreased resistance at 50 mm of extension by ca. 29, 39, and 6.5%, respectively (Rosell et al., 2001). Extensibility was increased by alginate (6%), HPMC (13%), and xanthan (11%). The differences may be due to the differences in resting time and the variation between the conditions of the two tests. The high level of xanthan gum increased Rmax by ca. 49% and decreased ERmax by ca. 51%, which suggests a stiffer dough. The medium level of xanthan gum also decreased ERmax by ca. 28% compared to control. Collar et al. (1999) found quadratic effects of xanthan gum on resistance to extension, but reported that this effect held no practical relevance. The amount of xanthan gum used in that study was also almost ten-fold smaller than the high level used in the present work, however.

3.2Bread properties

3.2.1 Specific volume and proof height

With the exception of CMC, all hydrocolloids increased specific volume of the whole wheat bread for at least one of the levels evaluated (Table 3, Figure 1). The findings for CMC and guar gum are in accordance with published works on whole wheat bread (Armero & Collar, 1996a; Mettler & Seibel, 1993). The most noticeable improvements were for the medium level of xanthan gum (ca. 13% increase) and all levels of HPMC (ca. 10.5-11% increase). In white dough, a comparison of alginate, xanthan, and HPMC found that 0.1% xanthan and HPMC both produced a similar increase to specific volume (Guarda et al., 2004). The increase due to alginate was not significant. Volume improvements can be related to increases in dough development and gas retention (Mettler & Seibel, 1993; Rosell et al., 2001). Alveograph tests of HPMC, xanthan, and alginate in white dough have shown that these hydrocolloids strengthen dough and improve the balance of elastic resistance and extensibility (Rosell et al., 2001). These hydrocolloids also improved dough stability during fermentation, preventing loss in dough volume over long fermentation periods. Guarda et al. (2004) reported that increasing the hydrocolloid addition from 0.1 to 0.5% provided an additional increase in loaf volume for HPMC but not for xanthan. In contrast, our work showed that increasing the amount of hydrocolloid further improved the specific volume for xanthan gum but not for HPMC. The present work used a greater increase in water absorption for increasing amounts of xanthan gum compared to Guarda et al. (2004), which likely allowed for the volume increase between the low and medium levels of xanthan gum. A similar trend of proof height was observed among the treatments. Generally, the samples with higher specific

Table 3 Weight, volume, specific volume, and moisture content of control and hydrocolloid-supplemented whole wheat bread

Treatment	Proof height (cm)	Weight (g)	Volume (cm^3)	Specific volume (cm^3/g)	Increase rate of specific volume vs. control (%)	Day 1 Moisture content (%)	Day 3 Moisture content (%)	Day 7 Moisture content (%)
Control	7.5	152.87	633	4.15		46.15	45.84	42.17
CMC low	7.6	153.26	658	4.30	3.67%	46.42**	46.17***	41.71
CMC med	7.8	153.42	663	4.33	4.34%	46.73***	46.51***	41.84
CMC high	7.7	154.29	655	4.25	2.45%	46.97***	46.81***	43.54
guar low	7.5	152.76	663	4.34	4.78%	46.35*	46.13**	42.49
guar med	8.0*	152.79	678*	4.44*	7.13%	46.68***	46.50***	42.54
guar high	7.9	155.11	683**	4.41	6.33%	47.19***	46.92***	42.92
HPMC low	8.0*	152.07	697***	4.58***	10.54%	46.54***	46.27***	42.65
HPMC med	8.0**	153.79	707***	4.60***	10.87%	46.76***	46.44***	41.87
HPMC high	7.9	153.47	703***	4.60***	11.09%	46.60***	46.34***	41.77
alginate low	8.1**	153.41	693**	4.52**	9.03%	46.98***	46.53***	42.22
alginate med	8.1**	155.82**	692**	4.44*	7.09%	47.38***	47.23***	43.51
xanthan low	7.9	153.03	697***	4.55**	9.84%	46.51***	46.21***	42.69
xanthan med	8.4***	154.80	723***	4.67***	12.76%	47.70***	47.40***	44.29
xanthan high	8.1**	155.93**	620	3.98	-4.06%	47.63***	47.42***	43.69

All means were compared to control. Level of significance indicated by * = 0.05 to 0.01, ** = 0.01 to 0.001, and *** = 0.001 and lower. Loaves were prepared in triplicate. Moisture content is average of six replicates.

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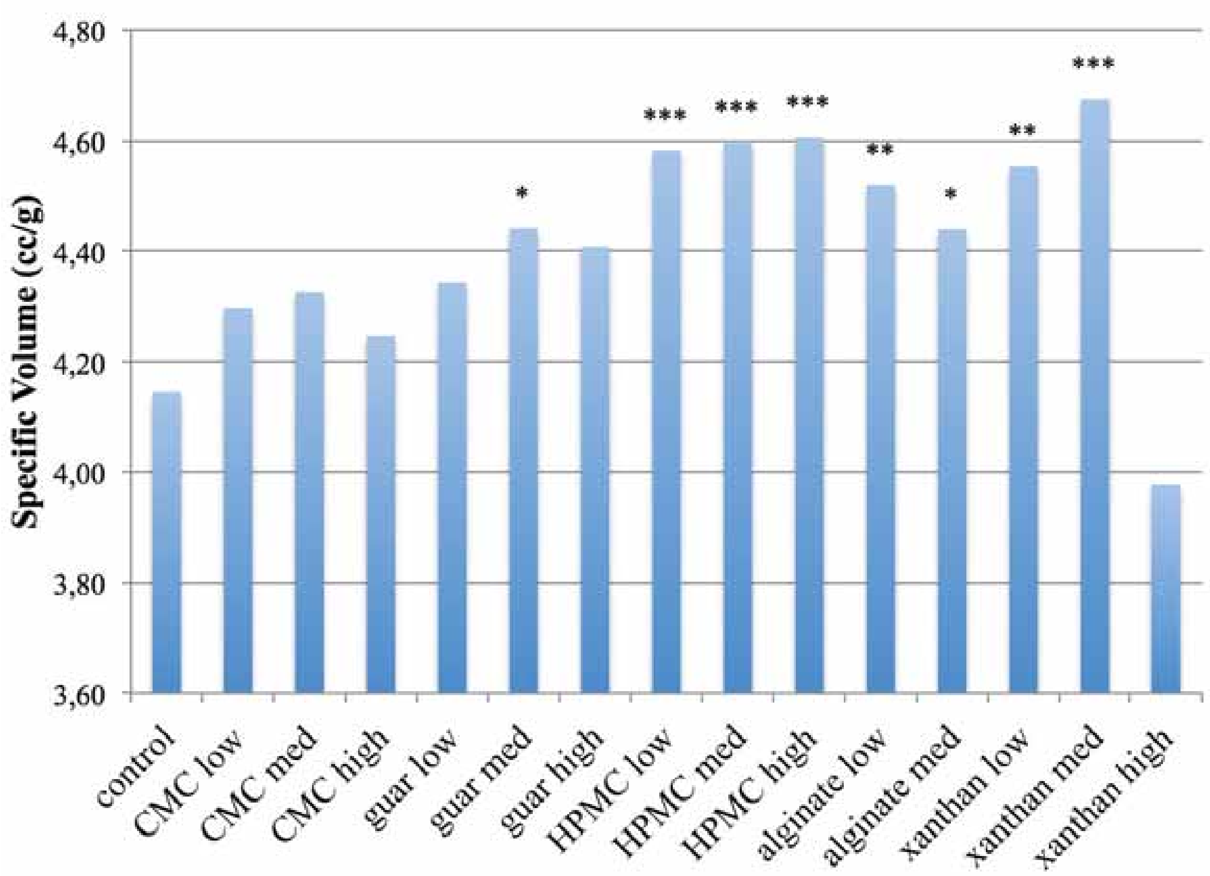

Sourcec / Graphic: Li et al 2021

Fig. 1: Specific volume of whole wheat bread with added hydrocolloids. Hydrocolloids were added on fwb at levels low = 0.25%, med = 0.5%, high = 1.0%. All means were compared to control. Level of significance indicated by * = 0.05 to 0.01, ** = 0.01 to 0.001, and *** = 0.001 and lower. Loaves were prepared in triplicate.

volume had higher height values than the control group (Table 3). Addition of hydrocolloids (except for CMC) at certain levels, such as xanthan at 0.1% (8.1 cm) and 0.5% (8.4 cm) significantly increased ($p < 0.01$) proof height in comparison with the control (7.5 cm).

The ability of hydrocolloids to improve loaf volume are often attributed to a strengthening effect on the gluten network and an improvement in gas retention. The exact mechanisms behind these effects are not well defined and vary between different types of hydrocolloids. Several attempts have been made to clarify the interactions between hydrocolloids and wheat flour constituents. The specific interactions depend on the type and level of hydrocolloid (Bárcenas et al., 2009; Linlaud et al., 2011; Ribotta et al., 2005). The interaction with gluten, the main structural component of bread, is of particular interest in explaining the effect of hydrocolloids on loaf volume. Such interactions include hydrogen bonding, in the case of neutral hydrocolloids like guar gum, and noncovalent linkages between amide groups of gluten and the hydroxyl groups of anionic hydrocolloids like xanthan gum and alginate (Linlaud et al., 2011; Ribotta et al., 2005). Hydrocolloids have been shown to alter the secondary structure of gluten proteins (Linlaud et al., 2011), which affects the gluten network. For example, SEM visualization of dough microstructure suggested that guar gum promoted a more integrated gluten network (Linlaud et al., 2009). In the case of HPMC, once hydrocolloid gelation occurs, it strengthens the gluten network and may partially replace protein within the network. This modification of the protein and integration into the structural network may explain the beneficial effects on loaf volume and other quality aspects of bread (Rosell & Foegeding, 2007). Due to an abundance of hydroxyl groups, xanthan gum interacts strongly with gluten and hence limits dough extension (Rosell et al., 2001; Zannini et al., 2014). However, 1H NMR re-

Table 4 Crumb structure analysis of control and hydrocolloid-supplemented whole wheat bread

Treatment	Number of cells	Cell wall thickness (mm)	Cell diameter (mm)
Control	3223	0.423	1.95
CMC low	3242	0.422	1.97
CMC med	3238	0.425	1.99
CMC high	3209	0.422	1.98
guar low	3248	0.426	1.99
guar med	3270	0.424	1.97
guar high	3292	0.425	2.02
HPMC low	3306	0.428	2.06
HPMC med	3417*	0.424	2.00
HPMC high	3293	0.430	2.08
alginate low	3269	0.429	2.06
alginate med	3171	0.428	2.03
xanthan low	3328	0.425	2.05
xanthan med	3359	0.428	2.12*
xanthan high	3205	0.419	1.87

All means were compared to control. Level of significance indicated by * = 0.05 to 0.01. Means are the average of three replicates.

Sourcec: Li et al 2021 / Graphic: ct 2021

laxation assays show that xanthan gum increases molecular mobility of dough, suggesting a less rigid gluten-hydrocolloid-water network, and FT-Raman analysis indicated a less ordered structure in the gluten network (Linlaud et al., 2011). SDS-PAGE revealed non-covalent crosslinking of gliadin proteins in the presence of xanthan gum, forming large, soluble aggregates. Xanthan gum also promoted the formation of a more entangled network (Linlaud et al., 2011), which was related to the more elastic characteristics of dough supplemented with xanthan gum (Linlaud et al., 2009).

3.2.2 Crumb structure

The hydrocolloids tested did not significantly affect crumb structure of the bread (Table 4, Figure 1), except for a modest increase in number of cells for the medium level of HPMC, and an increase in cell diameter for the medium level of xanthan gum. Zannini et al. (2014) also found that xanthan gum and HPMC had no effect on number of cells or cell size, but did report a decrease in cell wall thickness. The difference could be due to the different bread-making methods or the type of HPMC used.

3.2.3 Textural properties of bread

TPA of bread on Day 1 revealed mostly non-significant reductions in crumb hardness as a result of hydrocolloids, except for significant reductions due to the high level of guar gum and the medium level of HPMC (Table 5). The initial softening effect of HPMC in whole wheat bread has been previously reported (Armero & Collar, 1996a; Zannini et al., 2014). The other textural parameters measured by TPA were also largely unaffected by hydrocolloid addition. The treatments that produced the largest loaf volume were not always the ones with the lowest values for crumb hardness, reinforcing the fact that although loaf volume is a major contributor to firmness (Armero, E. & Collar, 1998; Mettler & Seibel, 1993), gas retention capacity and increased water absorption of dough (Zannini et al., 2014) and the specific nature of the crumb also play a role in the resistance of crumb to compression (Armero & Collar, 1996a).

Differences in crumb hardness became more apparent with storage time. The increase in hardness with the high level of xanthan at Day 3 could be caused by the low loaf volume compared to the low and medium treatments of the same gum (Armero & Collar, 1998). The increased hardness can also be caused by a lack of water for plasticizing the gluten network (Goesaert et al., 2009), since the water absorption was the same for the high and medium levels of xanthan gum. HPMC, alginate, and the low and medium levels of xanthan gum all showed a trend for decreasing the rate of staling, based on the rate of increase in crumb hardness over time. The anti-staling effect of HPMC could result from its ability to hinder interactions among the other components in the crumb by enveloping them in a polymer network (Bárcenas & Rosell, 2005) and by its preferential binding to starch, which influences the interactions among lipid, starch, and gluten (Collar et al., 1998). Xanthan gum and alginate soften bread crumb by interfering with starch-gluten interactions (Davidou et al., 1996). Alginate decreases the gelatinization temperature of starch, which allows a longer window during which amylases can act on the starch (Rojas et al., 1999). Amylases are commonly added either by malted barley flour

Table 5 Texture profile analysis of control and hydrocolloid-supplemented whole wheat bread after 1d storage at 22 °C, change in hardness after 3 and 7d storage, and rate of bread firming during storage

Treatment	Hardness, (N)	Resilience, (%)	Cohesion	Springiness, (%)	Chewiness, (N)	Day 3 Hardness, (N)	Day 7 Hardness, (N)	Slope: rate of firming	R^2
Control	3.63	35.4	0.715	95.2	2.46	4.97	8.14	0.758	0.808
CMC low	3.32	34.9	0.715	95.6	2.26	4.35	7.44	0.699	0.832
CMC med	3.56	34.7	0.711	95.9	2.43	4.88	8.26	0.792	0.898
CMC high	3.42	33.9*	0.698*	95.2	2.27	4.82	7.90	0.749	0.875
guar low	3.58	35.8	0.715	95.0	2.43	4.92	8.29	0.792	0.689
guar med	3.53	35.8	0.715	95.6	2.40	4.69	7.49	0.667	0.779
guar high	3.05*	35.7	0.714	96.0	2.02**	4.26*	6.98	0.658	0.853
HPMC low	3.23	35.9	0.718	95.7	2.22	4.45	6.92	0.615	0.803
HPMC med	2.91**	36.5	0.722	95.2	2.00**	4.12**	6.27*	0.557	0.864
HPMC high	3.17	36.2	0.720	95.7	2.18	4.42	7.07	0.652	0.882
alginate low	3.57	36.0	0.717	95.8	2.45	4.53	6.63	0.512	0.858
alginate med	3.89	35.2	0.708	95.2	2.61	5.33	7.53	0.599	0.776
xanthan low	3.20	35.7	0.718	95.7	2.18	4.29*	6.85	0.614	0.848
xanthan med	3.31	36.7*	0.723	96.4	2.29	3.94***	6.13**	0.482	0.719
xanthan high	4.04	35.3	0.710	96.1	2.74	5.94**	8.55	0.737	0.756

All means were compared to control. Level of significance indicated by * = 0.05 to 0.01, ** = 0.01 to 0.001, and *** = 0.001 and lower. Six replicates were analyzed per treatment.

Sourcec: Li et al 2021 / Graphic: ct 2021

or from fungal sources, and prolonging their action would contribute to an anti-staling effect. Furthermore, amylograph analysis revealed that alginate increased the formation of the amylose-lipid complex, which is associated with a softening of the crumb (Rojas et al. 1999). Water retention capacity and starch interactions have also been proposed to explain the softening effects of hydrocolloids (Collar et al., 1998; Guarda et al., 2004).

3.2.4 Moisture content

Hydrocolloids increased crumb moisture content of fresh bread (Table 3), in accordance with Guarda et al. (2004). An increase in moisture content of the fresh bread was expected, since all of the hydrocolloids increased the water absorption of the dough to varying degrees due to their high water-binding capacities. None of the treatments displayed significant differences in moisture content compared to control after 7 days of storage, although the trend for increasing moisture content with hydrocolloids was still observed. Guarda et al. (2004) reported increased moisture retention in bread supplemented with hydrocolloids.

3.2.5 Starch retrogradation

The present work did not reveal any significant changes to the endothermic transitions of bread crumb due to hydrocolloid addition (Table 6). These results suggest that the hydrocolloids did not modify starch retrogradation, at least not consistently or significantly. These findings are in contrast with certain published studies on the use of hydrocolloids as anti-staling agents in white bread. In white bread, HPMC retarded staling by decreasing the retrogradation index (Bárcenas & Rosell, 2005). When used in combination with high ester pectin, xanthan gum reduced the amount of amylose-lipid complex, which would promote bread staling (Collar et al., 1999). In whole wheat flatbread, which has a lower moisture content than pan bread, guar gum decreased the extent

Table 6 Retrogradation parameters for whole wheat bread with added hydrocolloids stored at 22 °C

Treatment	Tm_1 onset (°C)	Tm_1 peak (°C)	ΔH_1 (J/g)	Tm_2 onset (°C)	Tm_2 peak (°C)	ΔH_2 (J/g)
Control	51.59	65.98	2.52	100.02	118.07	1.71
CMC low	51.19	64.70	2.19	96.05	115.24	1.31
CMC med	50.51	62.71	2.04	96.81	113.88	0.93
CMC high	50.35	63.96	2.77	96.50	114.76	1.21
guar low	50.94	64.22	2.45	99.72	116.75	1.25
guar med	50.70	64.03	2.63	96.71	117.24	1.51
guar high	50.94	64.69	2.23	97.59	115.21	1.28
HPMC low	51.59	65.35	2.69	98.25	118.06	1.36
HPMC med	50.79	64.00	2.52	99.90	117.89	1.80
HPMC high	50.46	63.98	2.81	96.71	116.50	1.37
alginate low	51.21	64.66	2.48	97.77	115.75	1.44
alginate med	51.43	65.54	2.56	101.40	119.02	1.32
xanthan low	50.93	64.53	2.57	96.28	116.08	1.72
xanthan med	51.26	63.12	2.10	98.75	114.46	0.74
xanthan high	51.20	64.09	2.26	98.43	113.86	0.80

All means were compared to control. Tests were performed in duplicate. No significant differences were found in comparisons of treatment means to control.

Sourcec: Li et al 2021 / Graphic: ct 2021

of amylopectin retrogradation (Shaikh et al., 2008). DSC analysis of wheat starch gels with either guar or xanthan gum found that xanthan gum decreased starch retrogradation (Biliaderis et al., 1997). Our previous work with xanthan gum in whole wheat bread found a decrease in amylose-lipid complexation, whereas amylopectin retrogradation was not changed (Tebben & Li, 2019). The current study did reveal a trend for decreasing amylose-lipid complexation, although this change was not significant at the 0.05 significance level ($p = 0.0838$ for medium and $p = 0.1134$ for high levels of xanthan). According to Davidou et al. (1996), alginate, xanthan gum, and locust bean gum had little effect on starch retrogradation or amylose-lipid complexation in white bread, although alginate did reduce somewhat the retrogradation of amylopectin under certain storage conditions. The differences observed in the present study compared to some literature could be due to the specific nature of whole wheat pan bread compared to the other systems such as white bread, flat bread, or addition of wheat germ, bran, or starch gels, or to the variation in the structure of the hydrocolloids. For instance, inclusion of whole wheat flour could accelerate starch retrogradation and bread staling compared to white flour sample, which may be attributed to the different lipase activities in the systems (Abdel-Haleem, 2019). The present findings confirm that amylopectin retrogradation is one of many aspects of bread staling, but not the only cause of crumb firming (Davidou et al., 1996; Hug-Iten et al., 2003; Martin et al., 1991).

4 Conclusions

Guar gum, HPMC, sodium alginate, and xanthan gum all effectively increased loaf volume of whole wheat bread without substantial alterations in crumb structure. CMC was not an effective hydrocolloid for improving the loaf volume or hardness and staling of whole wheat bread. HPMC, sodium alginate, and xanthan gum decreased the rate of crumb firming but did not alter amylopectin retrogradation. HPMC at 0.5% fwb is recommended as the ideal hydrocolloid for whole wheat bread, promoting an increase in volume and decrease in crumb firmness and staling. HPMC reduced the mixing time and did not substantially alter water absorption of the dough, unlike xanthan gum. With any hydrocolloid, care must be taken to optimize the water absorption and mix time of the dough to the particular type and level of the improver in order to benefit loaf volume and crumb texture. This study examined the individual effects of hydrocolloids, and a previous study examined the individual effects of different enzymes (Tebben et al., 2020). For further improvement to loaf volume, future work should examine the combination of hydrocolloids with emulsifiers and/or enzymes.

Conflict of interest

The authors declare no conflict of interest.

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