Title	Evaluation of a new method to determine the water addition level in gluten-free bread systems
Author(s)	Sahin, Aylin W.; Wiertz, Jessica; Arendt, Elke K.
Publication date	2020-04-01
Original citation	Sahin, A. W., Wiertz, J. and Arendt, E. K. (2020) 'Evaluation of a new method to determine the water addition level in gluten-free bread systems', Journal of Cereal Science, 93, 102971 (8 pp). doi: 10.1016/j.jcs.2020.102971
Type of publication	Article (peer-reviewed)
Link to publisher's version	http://www.sciencedirect.com/science/article/pii/S0733521019309816 http://dx.doi.org/10.1016/j.jcs.2020.102971 Access to the full text of the published version may require a subscription.
Rights	**© 2020 Elsevier Ltd. All rights reserved. This manuscript version is made available under the CC BY-NC-ND 4.0 license.** https://creativecommons.org/licenses/by-nc-nd/4.0/
Embargo information	Access to this article is restricted until 12 months after publication by request of the publisher.
Embargo lift date	2021-04-01
Item downloaded from	http://hdl.handle.net/10468/9871

Evaluation of a new method to determine the water addition level in gluten-free bread systems

Aylin W. Sahin [a], Jessica Wiertz[b], Elke K. Arendt [c]*

[a] School of Food and Nutritional Sciences, University College Cork, Ireland

[b] Brabender GmbH & Co. KG, Duisburg, Germany

[c] School of Food and Nutritional Sciences and APC Microbiome Institute, University College Cork, Ireland

*Corresponding author: Elke K. Arendt; Mailing address: School of Food and Nutritional Science, University College Cork, Western Road, Cork, Ireland; Phone: +353-21-4902064; Fax: +353-21-4270213; Email: e.arendt@ucc.ie

Keywords: gluten-free, water adjustment, Farinograph, water hydration capacity, hydrocolloids

Abstract

The water content in gluten-free recipes plays an essential role in the resulting product quality. Up to date the water adjustment is conducted mainly by trial-and-error. Brabender GmbH & Co. KG developed an attachment for the Farinograph, which makes the measurement of batter consistencies feasible. The water content was adjusted using this new tool and compared to the water determined based on the water hydration capacity (WHC) of the single bulking ingredients. Furthermore, bread quality characteristics were analysed. Five different hydrocolloids were tested in a gluten-free system based on rice flour. Water levels differed significantly, when guar gum (20% water) or sodium alginate (18% water) were incorporated. The use of Farinograph resulted generally in a higher specific volume (+ 0.63 ml/g) and a softer crumb (-16 N). On the contrary, the WHC-method only gave an indication about the water addition but did not consider temperature changes during mixing and its effect on the hydration. In conclusion, Farinograph can be considered as a useful tool for the determination of the optimal water content, and additionally provides useful information about batter stability and dough development time.

1. Introduction

Coeliac disease is a condition resulting in a reaction to the protein gluten. The prevalence of the disorder has increased over recent years (Lohi et al., 2007) and an effective management of the condition relies on following a gluten-free diet (Lebwohl et al., 2018). Wheat bread is consumed globally and has an important role in nutrition, providing several macronutrients and micronutrients. Gluten is a protein present in wheat that plays several roles in breadmaking. Without gluten, lower quality breads are generally produced, encouraging research to improve the characteristics of gluten-free products (Hager and Arendt, 2013).

Studying water absorption properties within gluten-free bread has been suggested to optimise the qualities of the breads (Horstmann et al., 2018). Incorporating water-soluble substituted polysaccharides such as hydrocolloids is recognised method of producing a stable network within gluten-free bread. Much research has displayed the possible usage of hydrocolloids in gluten-free recipes. With the addition, the structure and texture of gluten-free bread can be enhanced and produced comparable wheat flour baked goods (Anton and Artfield, 2008).

For wheat bread systems a standardised method using Farinograph is used to adjust the dough consistency by the addition of water. Farinograph is the most common used machine for the determination of the water absorption of flour. Furthermore, it determines dynamic changes in dough properties during the mixing process and evaluates the dough development time, dough stability and the degree of dough softening (D’Appolonia and Kunerth, 1984). For wheat doughs a consistency of 500 BU, which is equal to 5 Nm in a mixing bowl containing 300 g of dough, represents the target torque (Huang and Wrigley, 2015).

To date a standard method to adjust the water content in gluten-free bread is missing. Horstmann et al., (2018) used a calculation based on the water hydration capacity of each single bulking ingredient of the bread formulation to adjust the water content in gluten-free breads including different hydrocolloids. However, Brabender GmbH & Co. KG developed a tool, FarinoAdd-S300, which makes it possible to measure batter consistencies of gluten-free bread formulations. This attachment reduced the volume of the mixing chamber and ensures a homogeneous mixing process.

In the present study, water contents of gluten-free bread formulations involving five hydrocolloids (HPMC, guar gum, locust bean gum, sodium alginate and xanthan gum) were determined by using the two different methods as stated above. The aim of this study is to evaluate the quality of the water adjustment methods by comparing the results of the gluten-free bread characteristics, such as specific volume, crumb texture and crumb structure, staling rate and colour.

2. Materials and Methods

2.1. Raw materials

All gluten-free batters contained 98% rice flour (Beneo GmbH, Germany) as a base and combined with 2% hydrocolloids. The level of hydrocolloid addition was chosen based on the outcome of the study conducted by Horstmann et al. (2018). The hydrocolloids tested are hydroxypropyl methylcellulose (HPMC) (J Rettenmaier, Germany), guar gum (Cargill, France), locust bean gum (Cargill, France), sodium alginate (Chemcolloids Ltd, Congleton, UK), xanthan gum (Kelco, Germany). For the preparation of gluten-free breads instant dried yeast (Bruggeman, Belguim), sugar (Siúcra, Ireland) and salt (Glacia British Salt Limited, UK) were included.

2.2. Determination of the water content in gluten-free batters

The water content is one of the most important parameters in breadmaking. For wheat bread Farinograph is the most common tool to adjust the water level. Yet, to date this equipment was not suitable to be used for gluten-free batters due to their sticky consistency and the resulting inhomogeneous mixing. Brabender GmbH & Co. KG recently developed an attachment, the FarinoAdd-S300, which overcomes this issue by limiting the volume of the kneading chamber and mixing in a closed system.

The water content of the control gluten-free bread recipe containing 98% rice flour and 2% HPMC was determined by introducing different water contents (90%, 95%, 100%, 105% and 110% based on flour and HPMC mixture) to the mixture and evaluating the bread quality, considering specific volume, crumb texture and crumb structure. As a result an optimal water content of 100% based on flour and hydrocolloid (total of 100%) as determined.

2.2.1. Method 1: Water adjustment of gluten-free batters based on calculation taking the water hydration capacity (WHC) of the single ingredients into account

The adjustment of the water content in gluten-free batters using the WHC of the single ingredients is based on two equations which were used by Horstmann et al. (2018). AACC method 56 - 30.01 was used to measure the water hydration capacity (WHC) of rice flour, guar gum, HPMC, locust bean gum, pectin, sodium alginate and xanthan gum with some modifications: samples (0.500 g ± 0.005 g) were mixed with 40 ml of distilled water using an Ultra-Turrax equipped with a S10N-5G dispersing element (Ika-Laborttechnik, Janke and Kunkel GmbH, Staufen, Germany) for 15 seconds. Afterwards the suspensions were shaken for 30 minutes at 1000 rpm using a platform shaker (UNI MAX 1010, Heidolph, Schwabach, Germany), followed by centrifugation at 2000 *g* for 15 min. WHC was expressed as gram of water retained per gram of solid, using the equation (1):

$$WHC\left[\frac{g\ of\ water}{g\ of\ sample}\right]=\left(\frac{W2-W1}{d\ (water)}\right)\times\frac{1}{W1} \qquad (1)$$

Where:

d (water) = density of water (= 1 g/ml)

W2 = weight of sediment

W1 = weight of sample

The values calculated were used in equation (2) to calculate the required water content of the gluten-free batters considering the WHC of the single ingredients as well as the WHC of the control mixture of 98% rice flour and 2% HPMC.

$$Water\ content\ [\%]=\left(\left(\frac{c1}{100\,\%}\times a\right)+\left(\frac{c2}{100\%}\times b\right)\right)\times\frac{d}{e} \qquad (2)$$

Where:

a = WHC of rice flour

b = WHC of hydrocolloid

c1 = percentage of flour used in the formulation based on dry ingredients (98%)

c2 = percentage of hydrocolloid used in the formulation based on dry ingredients (2%)

d = 100% (based on rice flour) - optimal amount of water added to the based formulation which was determined in pre-trials

e = WHC of the base formulation 98% rice flour + 2% HPMC (control)

2.2.2. Method 2: Adjustment of the water content of gluten-free batters using Farinograph-TS including FarinoAdd-S300

As mentioned above, the water content of the control gluten-free bread recipe containing 98% rice flour and 2% HPMC was determined by the evaluation of the bread quality when different water levels were added. Hence, firstly the consistency of the control recipe, shown in Table 1, was measured using the Farinograph, and the resulting consistency of 103 BU was used as a target torque for all recipes. All Farinograph measurements were conducted using 200 g dry ingredients (based on 14% moisture), the chamber temperature was maintained at 30 °C and a kneading speed of 63 rpm (standard Farinograph procedure) was set. For Farinograph measurements the recipes including salt and sugar were used; onlyyeast was omitted.

2.3. Gluten-free bread preparation

Gluten-free bread was prepared following the procedure reported by Horstmann, Axel, and Arendt (2018). The bread formulation consisted of: 98% rice flour, 2% hydrocolloid, 2% salt, 4% sugar, 2% yeast and the determined water content; all based on 98% flour + 2% hydrocolloid (100% in total). The amount of water added depended on the calculated optimal content considering the WHC or the determined water level using the Farinograph, respectively. Active dried yeast was activated in 25 ºC water for 10 minutes. A k-beater (Kenwood, Havant, UK) was used for mixing at speed 1 for 1 min in a Kenwood Major Titanium 020 Mixer (Kenwood, Havant, UK). The batter was scraped down from the bowl walls after the first mixing, followed by a second mixing step at speed 2 for 2 min. 300 g of batter was weighed into baking tins of 16.5 cm x 11 cm x 7 cm and put in a proofer (KOMA, Netherlands) for 45 minutes at 30 ºC and 85% relative humidity (RH). Afterwards, the proofed batters were baked at 215 ºC top and bottom heat for 55 minutes in a deck oven (MIWE, Germany), steamed prior with 0.7 L of water. The breads were allowed to cool for 2 hours before analysing.

2.4. Bread properties

2.4.1. Specific volume

For the evaluation of the specific volume a 3D laser scan using a VolScan Profiler 300 (Stable Micro Systems, Godalming, UK) was performed.

2.4.2. Crumb texture and staling rate

The crumb texture was analysed using a TA-XT2i texture analyser (Stable Micro Systems, Godalming, UK). Therefore, gluten-free breads were sliced transversely with a thickness of 20 mm. To mimic the chewing activity of the mouth, a two-compression test was performed using a 20 mm cylindric probe, a test speed of 5 mm/s, a trigger force of 0.2 N and a compression distance of 10 mm. The hardness, springiness and the cohesiveness were evaluated 2 h after baking. In addition, the hardness after 24 h was determined to calculate the staling rate using the formula below.

$$Staling\ rate = \left(\frac{crumb\ hardness\ after\ 24\ h\ [N] - crumb\ hardness\ after\ 2\ h\ [N]}{crumb\ hardness\ after\ 2\ h\ [N]}\right)$$

2.4.3. Crumb structure

C-cell Bread Imaging System (Calibre Control International Ltd., Warrington, UK) was used for the investigation of the crumb structure and the number of cells, the average cell diameter and the average thickness of the cells was evaluated.

2.4.4. Crust and crumb colour

The colour of the crust and of the crumb was determined using a hand-held colorimeter (Minolta CR-331, Konica Minolta Holdings Inc., Osaka, Japan) based on the CIE colour model. To investigate the differences in colour caused by the incorporation of hydrocolloids other than HPMC, the ΔE value was calculated using the equation:

$$\Delta E = \sqrt{(L_2^* - L_1^*)^2 + (a_2^* - a_1^*)^2 + (b_2^* - b_1^*)^2}$$

Where: L_2^* = lightness value of the bread sample

L_1^* = lightness value of the control bread (bread including HPMC)

a_2^* = a* value of the bread sample; a_1^* = a* value of the control bread

b_2^* = b* value of the bread sample; b_1^* = b* value of the control bread

2.4.5. Statistical analysis

All analyses were performed in triplicates. A variance analysis (one-way ANOVA, $p \leq 0.05$, Tukey test) was performed using Minitab 17.

3. Results

3.1. Determination of the water content

The determination of the optimal water content was conducted using two different approaches: 1) Calculation of the optimal water content for gluten-free bread including different hydrocolloids based on the water holding capacity of the single ingredients; 2) Adjustment of the optimal water content using Farinograph-TS with the FarinoAdd-S300.

Firstly, the optimal water content of the control recipe was determined by the incorporation of 90%, 95%, 100%, 105% and 110% water based on 98% rice flour and 2% HPMC followed by the evaluation of the bread quality. The addition of 90% and 95% water resulted in torques of 171 BU and 131 BU respectively. Both breads showed relative small specific volumes (1.31 ± 0.15 ml/g and 1.46 ± 0.19 ml/g) in combination with a high number of cells (2258 ± 11 and 2207 ± 73) and the smallest average cell diameters (1.53 ± 0.08 mm and 1.92 ± 0.14 mm).

The incorporation of 100% water resulted in a batter consistency of 103 BU and showed a specific volume of 2.13 ± 0.05 ml/g and a crumb hardness of 10.65 ± 1.48 N.

The addition of more than 100% water led to a decrease in batter consistency (105% water addition: 82 BU; 110% water addition: 57 BU). Furthermore, the increased water content caused a decrease in specific volume (105% water: 2.10 ± 0.03 ml/g; 110% water: 1.80 ± 0.04 ml/g) and an uneven distribution of cells in the crumb reflected by bigger cell diameters (105% water: 2.83 ± 0.11 mm; 110% water: 3.46 ± 0.12 mm).

Taking all bread characterizing parameters into consideration, an optimal water content of 100% based on flour + HPMC was determined.

The water holding capacity (WHC) of the single hydrocolloids, rice flour and the mixture of the control (98% rice flour + 2% HPMC) is demonstrated in Table 1. The WHC of the control mixture 98% rice flour and 2% HPMC was 1.58 ± 0.01 g/g which was used in formula (2) representing the variable ‘e’.

The results of both methods are illustrated in Table 2, which also included the comparison of the two methods (water level determined by Farinograph – water level determined by calculation) expressed as 'Δ water content'. The incorporation of guar gum or sodium alginate as hydrocolloids showed significant different results in optimal water level comparing the two methods with each other. Regarding guar gum, the Farinograph method determined 20.25% less water addition compared to the calculated water level based on the WHC. On the contrary, the evaluation of sodium alginate in the Farinograph resulted in 18.05% more water compared to the calculation based on the WHC. Locus bean gum as well as xanthan gum only showed minor differences in water amount comparing the two methods with each other.

Furthermore, Farinograph measurements gave additional information about the gluten-free batter, such as the stability of the batter during mixing (S1 – S2) and dough development time (DDT), which are illustrated in the Farinograms in Figure 1. The highest batter stability was determined for the control (HPMC) (S = 1.22 min), followed by batter including xanthan gum (S = 1.05 min), while batter with locus bean gum resulted in the lowest stability (S = 0.37 min). The dough/batter development time (DDT) is a parameter which is of interest for the development of gluten-free bread in relation to the mixing procedure. The use of HPMC or xanthan gum resulted in the longest batter development time (1.22 min), whereas batter with locus bean gum had a very short development time (0.45 min). Furthermore, the torque development of the batters showed significant differences. Batter with HPMC showed a stretched peak, while locus bean gum resulted in a sharp peak. The highest torque decline after reaching the peak was determined in batters including guar gum and xanthan gum.

3.2. Gluten-free bread quality

In order to compare the two methods for the water adjustment with each other, gluten-free breads with the respective determined water content were baked and the bread quality was evaluated considering bake loss, specific volume, texture, crumb structure, colour as well as water activity. A highly consumer accepted bread is characterized by a high specific volume, soft crumb and equally distributed crumb cells without holes in the crumb.

3.2.1. Specific volume

The specific volume is an important parameter describing bread quality. Preferably, a high specific volume is aimed for. The comparison of the specific volumes of the breads is illustrated in Table 3. The water adjustment by using Farinograph-TS with the FarinoAdd-S300 showed generally a higher specific volume (+0.08 ml/g to +0.28 ml/g) compared to breads which water content was adjusted by calculation. However, breads including guar gum showed a higher specific volume when the water content was calculated based on WHC. Breads with HPLC showed the highest specific volume among all breads (2.13 ± 0.05 ml/g), followed by sodium alginate with a water content adjusted by the Farinograph method (2.18 ± 0.14 ml/g).

3.2.2. Crumb texture

The texture is an important characteristic of bread crumbs. Good-quality fresh bread is characterised by a soft and springy crumb (Cauvain, 2004). The values of the crumb texture are shown in Table 3.

The control bread using HPMC resulted in a crumb hardness of 10.26 ± 1.48 N. Water adjustment using Farinograph showed generally a decrease in hardness, especially when sodium alginate was used (-16.02 N compared to WHC method). Interestingly, when guar gum was applied as a hydrocolloid, bread crumbs adjusted by WHC method were significantly softer compared to the results obtained using the Farinograph method.

The staling rate, which is an indication of shelf life and hence an important parameter in terms of consumers' acceptance, showed lower values when the water content was adjusted by Farinograph. The lowest staling rate was determined in breads with xanthan gum using the Farinograph (0.79 ± 0.27).

Springiness indicates the recovery of the crumb to its original height after the first compression. A value of 1 represents a full recovery of the crumb. The higher the springiness the higher the quality of the bread. Except for guar gum, the adjustment of the water level by Farinograph resulted in higher springiness. Overall sodium alginate in combination with the Farinograph method showed a springiness value of 1.00 ± 0.01 which means that the crumb recovered fully after the first compression and represents a good-quality bread crumb.

The cohesiveness of a bread crumb indicates how well the crumb withstands a second compression. Comparing the two methods for water adjustment the bread crumbs did not differ significantly regarding cohesiveness. However, using the Farinograph resulted in slightly higher values. The highest cohesiveness was determined in bread crumbs including locus bean gum (0.74 ± 0.02) or sodium alginate (0.74 ± 0.02) in combination with the Farinograph.

3.2.3. Crumb structure

The internal crumb structure is another essential parameter to evaluate bread quality. Figure 2 shows the different breads and their crumbs. Number of cells, cell diameter and cell wall thickness are the most common characteristics to evaluate the internal structure of bread.

As demonstrated in Table 3, the water adjustment conducted by Farinograph resulted in a higher number of cells when guar gum, locus bean gum or xanthan gum were used. Breads including sodium alginate as a hydrocolloid led to a significant decrease in number of cells (- 401 cells) when Farinograph was used. Compared to the bread with HPMC (2172 ± 166), locus bean gum caused the most similar number of cells (2062 ± 87).

The cell diameter reflects the size of the cells. The control bread (including HPMC) had an average cell diameter of 2.29 ± 0.31 mm. Breads including locus bean gum or sodium alginate and a water content adjusted by Farinograph resulted in the same average cell diameter as the control (2.26 ± 0.24 mm; 2.37 ± 0.29 mm respectively). Xanthan gum, regardless the method used to determine the water content showed significantly lower cell diameters (1.47 ± 0.12 mm (WHC); 1.50 ± 0.17 mm (Farinograph)). On the contrary, the method used for water adjustment significantly influenced the cell diameter in breads including sodium alginate (1.40 ± 0.20 mm (WHC); 2.37 ± 0.29 mm (Farinograph)).

The cell wall thickness of all samples ranges between 0.41 and 0.52 μm. Even though it can be considered as a narrow range, significant differences occurred. Generally, the using the water level determined by Farinograph resulted in thicker cell walls with sodium alginate showing the thickest wall (0.52 ± 0.02 μm). Interestingly, using the WHC method resulted in the thinnest cell walls when sodium alginate was used as a hydrocolloid (0.41 ± 0.02 μm). In control breads (HPMC) a wall thickness of

0.48 ± 0.02 μm was determined which showed no significant differences compared to bread including locus bean gum, regardless the water-adjustment-method used.

3.2.4. Crust and crumb colour

Colour formation occurs due to Maillard reaction and caramelisation in which the water content plays a significant role. The results of the crust and crumb colour are demonstrated in Figure 3. Regarding the crust, the adjustment of the water content by Farinograph caused a higher L*-value, which indicates a lighter crust. The highest L*-values of the crust were determined in breads including xanthan gum (59.44 ± 2.08) or guar gum (58.38 ± 1.57). Furthermore, the crust of the breads showed more red shades, indicated by the a*-value, when Farinograph was used for water adjustment. However, guar gum in combination with the WHC-method resulted in the same a*-value as the control (HPMC) (17.33 ± 1.08). Increased yellow crust colour was determined in breads containing guar gum or xanthan gum in combination with the water adjustment by Farinograph, indicated by higher b*-values compared to the other breads. The differences in crust colour compared to the control (HPMC) bread, considering all three values (L*, a* and b*) is represented by ΔE in the graph A. The biggest difference was detected in breads including guar gum (14.58 ± 3.39) or xanthan gum (15.64 ± 3.87) in combination with the Farinograph-method, while locus bean gum showed the smallest difference (5.88 ± 2.86).

The L* value of the crumb was the highest in breads including guar gum (80.82 ± 2.00) or xanthan gum (82.86 ± 1.81) and the water content determined by Farinograph, while the lowest L*-value (crumb) was detected in bread with locus bean gum (69.75 ± 2.72) as a hydrocolloid in combination with the WHC-method. Regarding the a*- and b*-values of the crumbs, both were determined to be relatively low and, hence, the crumb appeared in light grey shades. The ΔE value of the crumb indicates the difference compared to the control (HPMC) bread. The biggest difference in crumb colour was measured in crumb including guar gum (11.44 ± 3.06) and xanthan gum (13.02 ± 3.42) and a water content adjusted by Farinograph. The smallest ΔE value was determined in crumbs including locus bean gum (3.72 ± 1.94) and guar gum (4.36 ± 3.10) in combination with the WHC-method.

4. Discussion

The water content used to prepare a gluten-free batter has an enormous impact on the quality of the final product. To date the adjustment of the water content in gluten-free batter was conducted either manually by trial-and-error or by calculation based on the water hydration capacity (WHC) of the bulk ingredients, such as flour, starch and hydrocolloids. Recently, Brabender GmbH & Co. KG developed an accessory for the Farinograph which reduces the volume of the mixing chamber and makes the measurement of the consistency of gluten-free batter feasible. This study compares the water adjustment using Farinograph and the FarinoAdd-S300 with a method used by Horstmann, Axel, and Arendt (2018) which is based on the WHC of the single bulk ingredients.

The WHC of the single hydrocolloids differed significantly among each other and showed similar values reported by Horstmann et al. (2018). The WHC of bulking agents, such as hydrocolloids, is influenced by their polar charge, their molecular weight as well as the number of branches in the molecule (Anton and Artfield, 2008; Capriles and Arêas, 2014). Since all hydrocolloids used are linear molecules, branching as an influencing factor of the WHC is not further discussed. Among the hydrocolloids used guar gum has a relatively high molecular weight, followed by xanthan gum. The high molecular weight increases the radius of gyration and, thus, the water holding capacity (Funami et al., 2005). HPMC and sodium alginate are relatively small molecules and, hence, resulted in a lower WHC.

The water contents determined by both methods led differed significantly, especially when guar gum or sodium alginate were used. Adjusting the water level of batters including guar gum by using the Farinograph resulted in a water content which was by 20.25% lower compared to the WHC-method. On the contrary, the Farinograph method showed an increased water content by 18.05% compared to the WHC-method in batter with sodium alginate. The influencing factor in these cases is the temperature (Pegg, 2012).While the WHC was determined at room temperature, Farinograph measurements were conducted in a temperature-controlled system at a temperature of 30 °C (standard method). Guar gum is known as a cold swelling hydrocolloid (Srichamroen, 2007). Thus, its viscosity and the associated torque of the batter is lower at higher temperatures, which resulted in a lower water content. Sodium alginate, on the other hand, is a hot swelling hydrocolloid, which led to a higher water content required for the batter when Farinograph was used (Horstmann et al., 2018).

Xanthan gum is a cold swelling hydrocolloid. However, the gluten-free batter showed a slightly increase in water content using the Farinograph-method, which is putatively due to interactions with the salt in the gluten-free batter system (Sworn, 2009). These interactions cause an increase in viscosity of xanthan which results an in overall increase in batter torque and hence more water to adjust the consistency to a target torque. It has to be noted that using the Farinograph provides the option to incorporate ingredients, such as salt, which might interact with the hydrocolloid during batter preparation and influence its viscosity. This can be considered as an advantage compared to the water adjustment based on the WHC.

Moreover, Farinograph measurements monitor the torque over time and give additional information about the batter. Based on the Farinogram illustrated in Figure 1, the use of different hydrocolloids caused different dough development times and different batter stabilities. The incorporation of locus bean gum resulted in a batter which is stable towards kneading for a very short time compared to HPMC or xanthan. This information can be used to adjust the mixing time and shorten it for batter including locus bean gum. Hence, the mixing process of gluten-free batter can be easily adjusted, which can improve the bread quality (Gómez et al., 2013).

Gluten-free batter including guar gum required less water when the content was adjusted using Farinograph, since it causes a decrease in viscosity with increasing temperature. A certain batter viscosity is required to ensure the retention of produced CO_2, which contributes to specific volume and crumb structure (Foschia et al., 2016). During the baking process, the temperature of the batter increases which causes a further decrease of the viscosity, when guar gum was included in the batter (Srichamroen, 2007). Hence, a smaller specific volume in combination with a denser crumb structure (higher number of cells with a smaller diameter), which caused a significant harder crumb, occurred when the water content adjusted by the Farinograph was used. The addition of more water, which was determined using the WHC-method resulted in a higher specific volume, but also less cells with a bigger cell diameter. The higher amount of water minimizes viscosity changes during proofing and, hence, the gluten-free batter system can retain produced CO_2 more efficiently compared to the batter adjusted by Farinograph. However, the decrease in cells in combination with the increase of cell size occurred due to the cells coagulation during the gluten-free bread preparation ((Marco and Rosell, 2008).

Gluten-free breads including sodium alginate in combination with the water content adjusted by Farinograph showed a higher bread quality reflected by a higher specific volume, a softer crumb texture and equally distributed cells in the crumb. As mentioned before, sodium alginate is hot swelling which means the viscosity increases with increasing temperature (Horstmann et al., 2018). Using the Farinograph for water adjustment in a temperature-controlled system at 30 °C, which represents also the temperature during proofing, ensures the swelling of sodium alginate to its maximum at this temperature and at the same time provides a high batter stability related to no changes in viscosity during proofing. Hence, the produced CO_2 can be retained in the batter which results in a high specific volume and a softer crumb. Furthermore, breads including sodium alginate reached an average springiness value of 1, which contributes to a high-quality bread crumb (Cauvain, 2004)

The water content in batters including locus bean gum showed only a slight difference when comparing the two methods. However, this small deviation resulted in a significantly different specific volume of the breads. On the contrary, the small difference in water content in batter with xanthan gum did not influence the bread quality.

5. Conclusion

This study showed a direct comparison of two methods for the adjustment of the water content in gluten-free batter and their effect on gluten-free bread quality. Generally, the water adjustment using Farinograph resulted in a higher quality bread. This Farinograph represents a temperature-controlled system, which showed reproducible results in a short time, and considers interactions of all ingredients. In this study a simplified gluten-free model system was used, while commercially available products usually include more than fifteen ingredients. Thus, the Farinograph is a useful tool for the determination of the water content of gluten-free recipes and, in addition, provides useful information, such as batter stability and dough development time during mixing. That extra information can be used for the adjustment of the process. Furthermore, the influence of different temperatures and mixing speeds, as well as speed profiles can be investigated.

Since the optimal consistency of gluten-free batter depends on the hydrocolloid and base ingredient used, a collection of target consistencies for different ingredient combinations, including basic ingredients, such as salt and sugar, could be established for a deeper inside of gluten-free batter.

6. Acknowledgement

The authors would like to thank Brabender GmbH & Co. KG. for providing the Farinograph-TS and the FarinoAdd-S300. Furthermore, the authors would like to acknowledge Mr Tom Hannon for his technical support and Mr Connor Logue for his contribution to this study.

7. References

Anton, A.A., Artfield, S.D., 2008. Hydrocolloids in gluten-free breads: A review. Int. J. Food Sci. Nutr. 59, 11–23. https://doi.org/10.1080/09637480701625630

Capriles, V.D., Arêas, J.A.G., 2014. Novel approaches in gluten-free breadmaking: Interface between food science, nutrition, and health. Compr. Rev. Food Sci. Food Saf. 13, 871–890. https://doi.org/10.1111/1541-4337.12091

Cauvain, S.P., 2004. Improving the texture of bread, in: Kilcast, D. (Ed.), Texture in Food: Solid Foods, Texture in Food. Woodhead Publishing, Cambridge, pp. 432–449.

D'Appolonia, B.L., Kunerth, W.H., 1984. Farinograph handbook. The Association of Cereal Chemistry, St. Paul.

Foschia, M., Horstmann, S., Arendt, E.K., Zannini, E., 2016. Nutritional therapy – Facing the gap between coeliac disease and gluten-free food. Int. J. Food Microbiol. 239, 113–124. https://doi.org/10.1016/j.ijfoodmicro.2016.06.014

Funami, T., Kataoka, Y., Omoto, T., Goto, Y., Asai, I., Nishinari, K., 2005. Food hydrocolloids control the gelatinization and retrogradation behavior of starch. 2a. Functions of guar gums with different molecular weights on the gelatinization behavior of corn starch. Food Hydrocoll. 19, 15–24. https://doi.org/10.1016/j.foodhyd.2004.04.008

Gómez, M., Talegón, M., de la Hera, E., 2013. Influence of Mixing on Quality of Gluten-Free Bread. J. Food Qual. 36, 139–145. https://doi.org/10.1111/jfq.12014

Hager, A.S., Arendt, E.K., 2013. Influence of hydroxypropylmethylcellulose (HPMC), xanthan gum and their combination on loaf specific volume, crumb hardness and crumb grain characteristics of gluten-free breads based on rice, maize, teff and buckwheat. Food Hydrocoll. 32, 195–203. https://doi.org/10.1016/j.foodhyd.2012.12.021

Horstmann, S.W., Axel, C., Arendt, E.K., 2018. Water absorption as a prediction tool for the application of hydrocolloids in potato starch-based bread. Food Hydrocoll. 81, 129–138. https://doi.org/10.1016/j.foodhyd.2018.02.045

Huang, W., Wrigley, C., 2015. Standardized Test Methods for Grains and Grain-Based Products, in: Wrigley, C.W., Corke, H., Seetharaman, K., Faubion, J. (Eds.), Encyclopedia of Food Grains. Elsevier Science & Academic Press, Oxford, pp. 300–308.

Lebwohl, B., Sanders, D.S., Green, P.H.R., 2018. Coeliac disease. Lancet 391, 70–81. https://doi.org/10.1016/S0140-6736(17)31796-8

Lohi, S., Mustalahti, K., Kaukinen, K., Laurila, K., Collin, P., Rissanen, H., Lohi, O., Bravi, E., Gasparin, M., Reunanen, A., Mäki, M., 2007. Increasing prevalence of coeliac disease over time. Aliment. Pharmacol. Ther. 26, 1217–1225. https://doi.org/10.1111/j.1365-2036.2007.03502.x

Marco, C., Rosell, C.M., 2008. Breadmaking performance of protein enriched, gluten-free breads. Eur. Food Res. Technol. 227, 1205–1213. https://doi.org/10.1007/s00217-008-0838-6

Pegg, A.M., 2012. The application of natural hydrocolloids to foods and beverages, in: Baines, D., Seal, R. (Eds.), Natural Food Additives, Ingredients and Flavourings, Woodhead Publishing Series in Food Science, Technology and Nutrition. Woodhead Publishing, pp. 175–196. https://doi.org/https://doi.org/10.1533/9780857095725.1.175

Srichamroen, A., 2007. Influence of temperature and salt on viscosity property of guar gum. Naresuan Univ. J. 15, 55–62.

Sworn, G., 2009. Xanthan gum, in: Phillips, G.O., Williams, P.A. (Eds.), Handbook of Hydrocolloids. Woodhead Publishing, pp. 186–203. https://doi.org/10.1533/9781845695873.186

Tables

Table 1: Water holding capacity (WHC) of the single hydrocolloids, rice flour and the combination 98% rice flour + 2% HPMC expressed as grams of water per one gram of sample.

Water holding capacity (WHC) [g water/g sample]	
98% rice flour + 2% HPMC	1.58 ± 0.01 (e)
100% Rice flour	1.42 ± 0.11 (e)
100% HPMC	7.60 ± 0.52 (c)
100% Guar gum	22.52 ± 0.16 (a)
100% Locus Bean gum	7.52 ± 0.21 (c)
100% Sodium Alginate	4.65 ± 0.05 (d)
100% Xanthan gum	14.73 ± 0.39 (b)

Table 2: Water contents used for the preparation of gluten-free breads determined by using the equation based on the water holding capacity (WHC) of the single ingredients or by using the Farinograph. Δ Water content reflects the difference in water content (Farinograph method – WHC method).

	[%] based on flour + hydrocolloid		
	Water content (based on WHC)	**Water content (Farinograph)**	**Δ Water content**
98% Rice flour + 2% HPMC	100* (e)		-
98% Rice flour + 2% Guar gum	110.70 ± 0.20 (a)	90.45 ± 0.01 (g)	- 20.25
98% Rice flour + 2% Locus bean gum	91.76 ± 0.27 (f)	90.90 ± 0.53 (g)	- 0.86
98% Rice flour + 2% Sodium alginate	88.13 ± 0.06 (h)	106.18 ± 0.01 (b)	+ 18.05
98% Rice flour + 2% Xanthan gum	100.86 ± 0.50 (d)	101.90 ± 0.09 (c)	+ 1.04

* Fixed water content based on baking pre-trials investigating the bread quality including different amounts of water (data not shown)

Table 3: Bread characteristics of gluten-free breads. Δ illustrated the difference of the values obtained by using the Farinograph method versus the WHC method.

	HPMC	**Guar gum**			**Locus bean gum**			**Sodium alginate**			**Xanthan gum**		
	Water content of 100 % based on flour+HPMC	WHC	Farinograph	Δ (=difference)	WHC	Farinograph	Δ (=difference)	WHC	Farinograph	Δ (=difference)	WHC	Farinograph	Δ (=difference)
Specific volume [ml/g]	2.13 ± 0.05 (a)	1.90 ± 0.11 (b)	1.56 ± 0.03 (c)	**- 0.34**	1.79 ± 0.06 (b)	2.07 ± 0.07 (a)	**+ 0.28**	1.55 ± 0.04 (c)	2.18 ± 0.14 (a)	**+ 0.63**	1.46 ± 0.02 (c)	1.54 ± 0.04 (c)	**+ 0.08**
Hardness [N]	10.26 ± 1.48 (d)	10.57 ± 1.44 (d)	25.70 ± 3.46 (a)	**+ 15.13**	15.47 ± 2.48 (c)	14.02 ± 1.70 (c)	**- 1.45**	25.51 ± 1.85 (a)	9.49 ± 1.51 (d)	**- 16.02**	17.89 ± 2.81 (b)	15.18 ± 1.51 (c)	**- 2.71**
Staling rate (in 24 h)	0.91 ± 0.27 (d)	2.17 ± 0.55 (a)	0.95 ± 0.18 (cd)	**- 1.22**	1.72 ± 0.38 (b)	1.25 ± 0.45 (c)	**- 0.47**	1.66 ± 0.31 (b)	1.27 ± 0.44 (c)	**- 0.39**	1.11 ± 0.27 (cd)	0.79 ± 0.27 (d)	**- 0.32**
Springiness	0.99 ± 0.02 (ab)	0.98 ± 0.02 (bc)	0.95 ± 0.02 (g)	**- 0.03**	0.97 ± 0.01 (cd)	0.97 ± 0.02 (cde)	**0**	0.96 ± 0.01 (def)	1.00 ± 0.01 (a)	**+ 0.04**	0.95 ± 0.01 (g)	0.96 ± 0.01 (def)	**+ 0.01**
Cohesiveness	0.68 ± 0.02 (cd)	0.69 ± 0.03 (c)	0.72 ± 0.03 (b)	**+ 0.03**	0.73 ± 0.03 (ab)	0.74 ± 0.02 (ab)	**+ 0.01**	0.72 ± 0.03 (b)	0.74 ± 0.02 (a)	**+ 0.02**	0.67 ± 0.03 (d)	0.66 ± 0.02 (d)	**- 0.01**
Number of cells	2172 ± 166 (cd)	2285 ± 295 (bc)	2374 ± 251 (ab)	**+ 89**	1990 ± 106 (d)	2062 ± 87 (d)	**+ 72**	2412 ± 178 (ab)	2011 ± 150 (d)	**- 401**	2417 ± 165 (ab)	2487 ± 203 (a)	**+ 70**
Cell diameter [mm]	2.29 ± 0.31 (a)	1.91 ± 0.48 (bc)	1.85 ± 0.60 (c)	**- 0.06**	2.19 ± 0.16 (ab)	2.26 ± 0.24 (a)	**+ 0.07**	1.40 ± 0.20 (d)	2.37 ± 0.29 (a)	**+ 0.97**	1.47 ± 0.12 (d)	1.50 ± 0.17 (d)	**+ 0.03**
Wall thickness [mm]	0.48 ± 0.02 (bc)	0.47 ± 0.03 (cd)	0.46 ± 0.04 (d)	**- 0.01**	0.48 ± 0.01 (bc)	0.49 ± 0.01 (b)	**+ 0.01**	0.41 ± 0.02 (e)	0.52 ± 0.02 (a)	**+ 0.11**	0.42 ± 0.01 (e)	0.43 ± 0.01 (e)	**+ 0.01**

Figure captions

Figure 1: Farinograms of gluten-free batter including different hydrocolloids with rice flour as a base.

Figure 2: Appearance of breads and bread crumbs.

Figure 3: Evaluation of colour of crust (A) and colour of crumb (B). L* illustrates the lightness value (0 = black; 100 = white), a* shows the shades green (negative values) to red (positive values) and b* demonstrates the shades blue (negative values) and yellow (positive values). ΔE evaluates the difference compared to the control taking L*-, a*-, and b*-value into account.

Figure 1

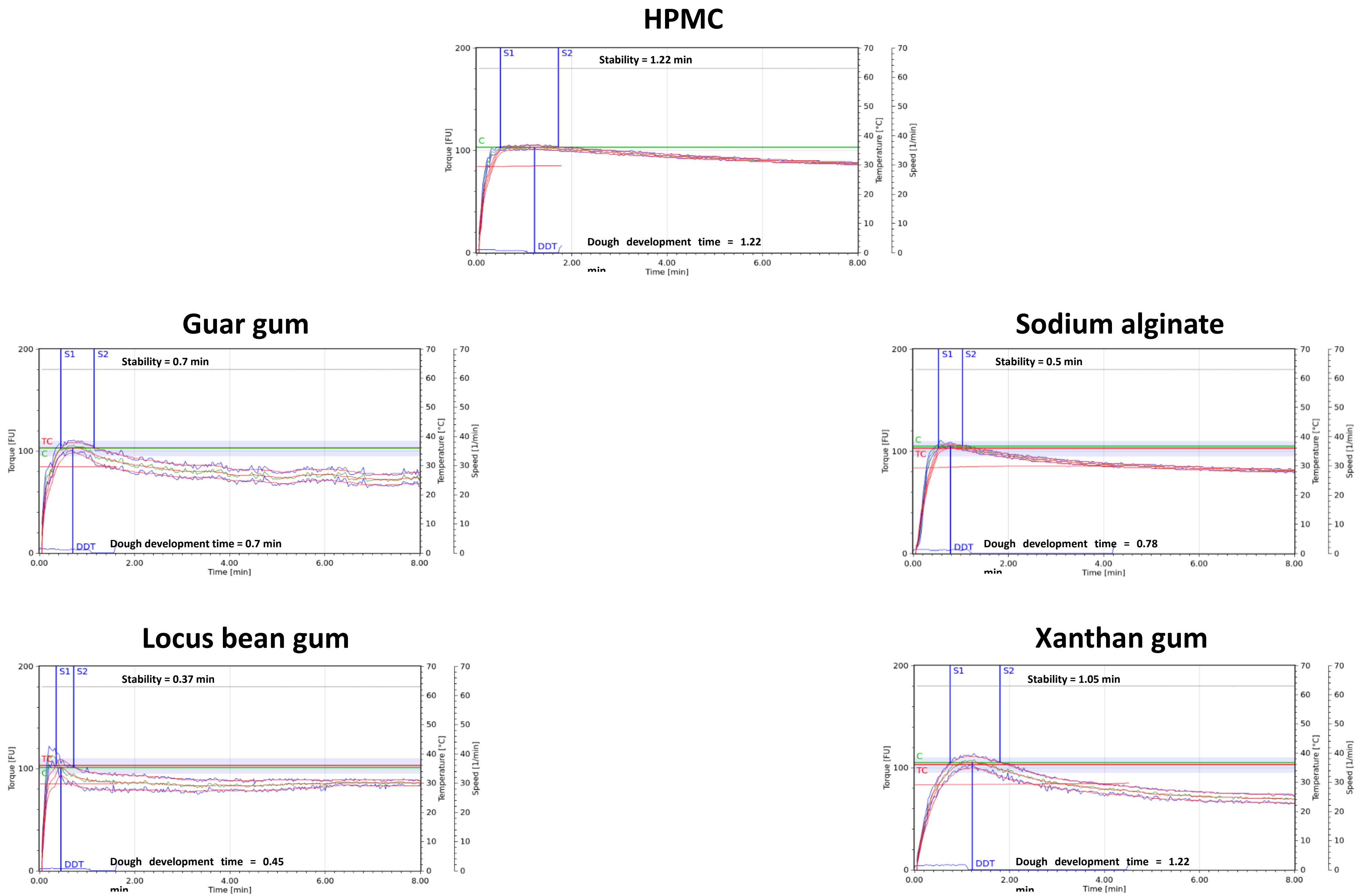

HPMC
Stability = 1.22 min
Dough development time = 1.22
Guar gum
Stability = 0.7 min
Dough development time = 0.7 min
Sodium alginate
Stability = 0.5 min
Dough development time = 0.78
Locus bean gum
Stability = 0.37 min
Dough development time = 0.45
Xanthan gum
Stability = 1.05 min
Dough development time = 1.22
S1
S2
C
TC
DDT
Torque [FU]
Temperature [°C]
Speed [1/min]
Time [min]

Figure 2

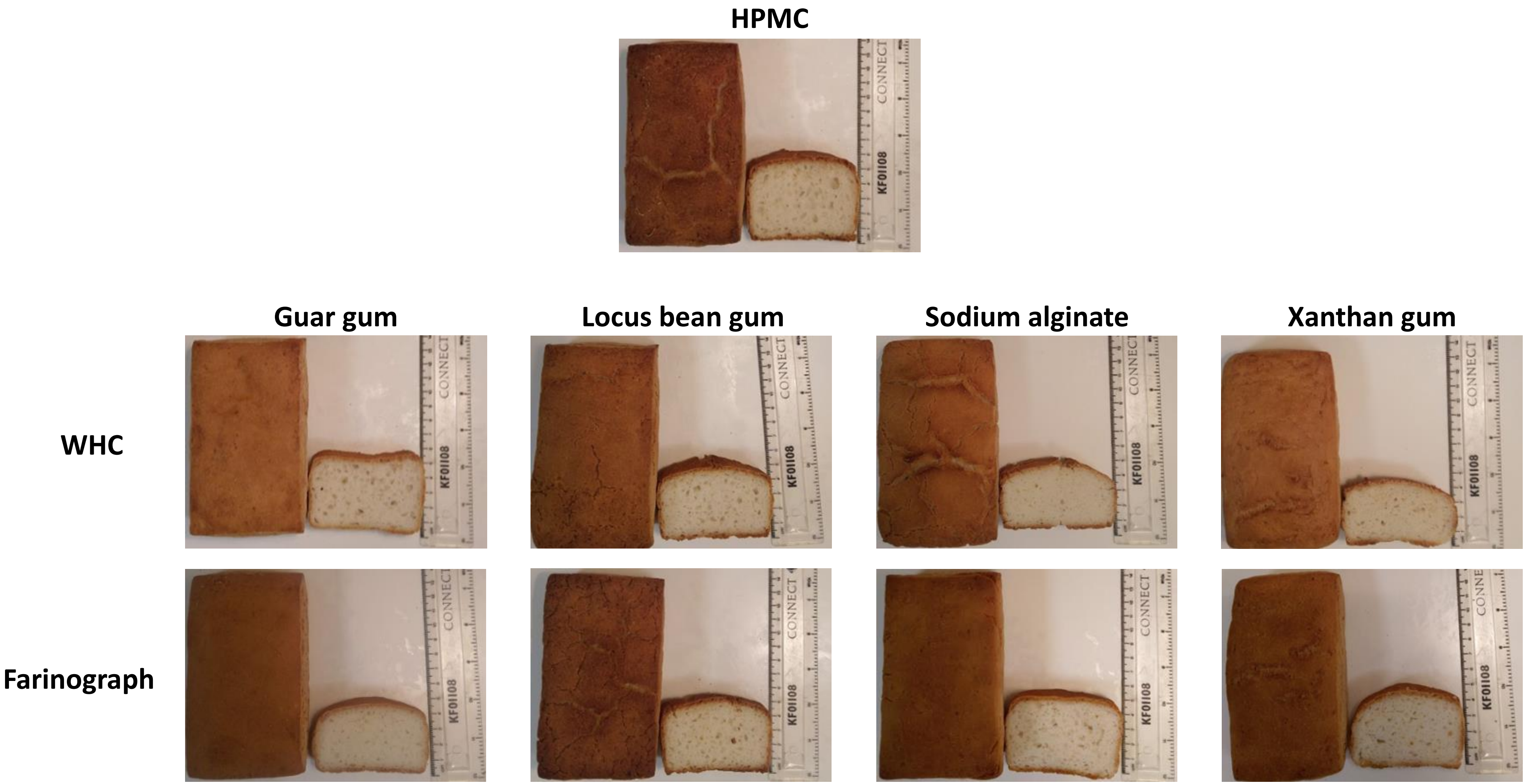
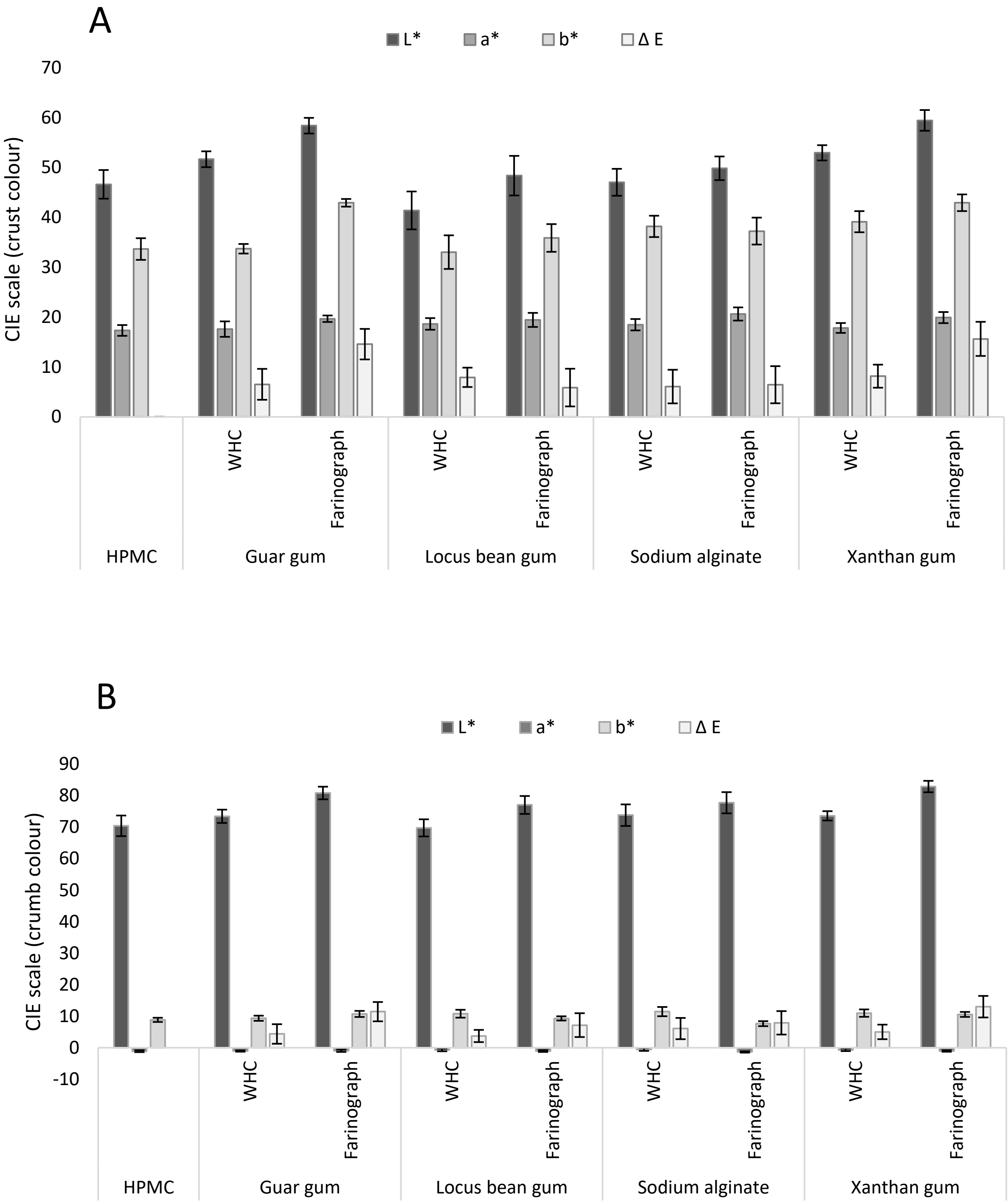

HPMC
Guar gum
Locus bean gum
Sodium alginate
Xanthan gum
WHC
Farinograph

Figure 3


A
L*
a*
b*
Δ E
CIE scale (crust colour)
70
60
50
40
30
20
10
0
WHC
Farinograph
HPMC
Guar gum
Locus bean gum
Sodium alginate
Xanthan gum
B
L*
a*
b*
Δ E
CIE scale (crumb colour)
90
80
70
60
50
40
30
20
10
0
-10
WHC
Farinograph
HPMC
Guar gum
Locus bean gum
Sodium alginate
Xanthan gum