**Exploring the potential of arabinoxylan as structuring agent in model systems for
gluten-free yeast-leavened breads**

Johanan Espinosa-Ramírez^{1,2}, Raquel Garzon¹, Sergio O. Serna-Saldivar², Cristina M.
Rosell^{1*}

¹ Institute of Agrochemistry and Food Technology (IATA-CSIC), C/ Agustin Escardino, 7,
Paterna 46980, Valencia, Spain.

² Centro de Biotecnología FEMSA. Escuela de Ingeniería y Ciencias, Tecnológico de
Monterrey, Av. Eugenio Garza Sada 2501 Sur, C.P. 64849 Monterrey, N. L., Mexico.

*Corresponding author e-mail: crosell@iata.csic.es. Phone number +34 963900022. Fax
number: +34 963636301

Abstract

Although the beneficial effect of arabinoxylan (AX) has been recognized for breadmaking, the available information about the effect of these compounds in gluten-free systems is scarce. In the present study, maize AX was tested in gluten-free breads using a yeast-leavened lean formulation based on rice flour and corn starch and two shaping models: pans and by dropping dough. The effect of the AX level (0%-5%) and hydration (70%-85%) were determined. Breads produced were analyzed in texture, morphology and crumb structure. The breads from the pan shaping model did not show significant differences in the crumb hardness. Moreover, the control breads presented better springiness, cohesiveness and resilience compared to AX breads. For the breads from the dropping dough model, those containing AX had lower hardness and chewiness and higher 2D area, height, cell density and surface area compared to control breads, especially at higher AX levels. Yet, AX caused a detrimental effect in springiness, cohesiveness and resilience. The hydration affected the hardness, 2D area, height, cell density and mean cell area in breads containing AX, finding better results in breads with 80% water absorption. This research demonstrated that even when AX are capable to improve the hardness and crumb structure of gluten-free breads, they could cause a detrimental effect in other textural characteristics.

Keywords: gluten free; bread; arabinoxylans; water absorption, rice flour

1. Introduction

Gluten proteins have been extensively identified as the determinant component for obtaining a cohesive and viscoelastic dough (Veraverbeke and Delcour, 2002). However, for the people who suffer celiac disease or gluten intolerance, gluten consumption should be waived. This need of a restrictive diet has led to the development of a great variety of gluten-free (GF) products for the growing GF market. The lack of a structuring agent in GF flours to replace gluten, yields doughs that are susceptible to collapse and unable to retain gas (Buksa, 2016; Onyango et al., 2011). Besides GF flours require a higher amount of water compared to wheat, leading to batter-like doughs that are difficult to handle and need to be poured in pans to avoid them becoming flat upon proofing and baking (Houben et al., 2012; Morreale et al., 2018; Schober et al., 2010). In fact, common defects include reduced volume, irregular crumb structure, dense areas or even large holes (McCarthy et al., 2005; Schober et al., 2008).

Hydrocolloids are often used as a gluten replacer to overcome the quality problems of GF breads (Ayala-Soto et al., 2017; Bourekoua et al., 2018; Lazaridou et al., 2007; McCarthy et al., 2005). These long-chain polymers, typically polysaccharides, fully or partially soluble, are prone to swell in water, which confers the needed viscosity to trap fermentation gases, making possible to produce GF breads with improved volume, texture and crumb structure (Houben et al., 2012). However, despite hydrocolloids control the water content and increase the viscosity of GF systems (Morreale et al., 2018), they are not consistent enough to retain the dough shape and containers are required to make fermented breads. Very scarce research has been carried out at lower water absorption levels that permit the production of GF breads in non-pan models (Schober et al., 2010). Therefore, models to

test the functionality of structuring agents should be designed to increase the shape variety in GF.

Arabinoxylans (AX) are hydrocolloids of polysaccharide nature, localized in the cell walls of the endosperm and the aleurone layer, and in the pericarp and testa of cereal grains (Izydorczyk and Biliaderis, 1995). The soluble fraction of AX has been recognized as a breadmaking improver due to their ability to increase dough viscosity and the stability of the batter structure after kneading, yielding softer breads with higher specific volume and better crumb features (Ayala-Soto et al., 2017; Bender et al., 2018; Biliaderis et al., 1995; Buksa et al., 2013; Courtin and Delcour, 2002). However, most of those studies using AX have been performed in wheat and rye breads and there is scarce information about the effect of these compounds in GF breads (Ayala-Soto et al., 2017; Bender et al., 2018). Likewise, rye is the source more frequently used to extract AX that are intended to be used in GF systems (Bender et al., 2018; Mansberger et al., 2014), despite it is a cereal considered hazardous for celiac disease diets. Ayala-Soto et al. (2017) extracted AX from maize fiber and evaluated their functionality in GF bread formulations finding higher specific volumes and softer crumb texture breads. Yet, to obtain the improved quality in AX breads these authors adjusted the water absorption for each formulation leading to hydration values of up to 105% when they used the higher AX level. Although it is recommended to adjust the water absorptions for the specific hydrocolloid being used (Morreale et al., 2018), the effect of hydrocolloids could be diminished or even non-existent at high hydrations due to the dilution effect promoted by the high amount of water (Mancebo et al., 2015). This makes difficult to discern whether the improvement effect was from water or the AX. Besides, the high amount of water limits the type of breads produced to pan-breads. Further evaluation of these compounds in fixed hydration conditions and

different shaping models could help to validate the potential of AX as structuring agent for GF breadmaking.

The aim of the present study was to evaluate the potential of AX from maize fiber to improve the texture and crumb structure of GF breads. Fixed hydrations among tests and a lean formulation were used in order to avoid confusion in the functionality of AX. In order to test the ability of the AX to hold the bread structure without the use of pans, in the present study, a breadmaking model based on dropping-dough onto a surface was also tested.

2. Material and methods

2.1 Materials

For the breadmaking process a blend of 80% rice flour (7.4% protein; 12.5% moisture) and 20% regular corn starch, was used as model flour. The rice flour and regular corn starch were purchased from Harinera La Meta S.A (Lleida, Spain) and Daesang Corporation (Dongdaemun, South Korea), respectively.

The maize arabinoxylans (AX) were obtained according to the methodology reported by Ayala-Soto et al. (2016) for pilot plant scale. Briefly, commercial fiber from white maize (Indumex, Sinaloa, Mexico) was suspended in 0.3 M NaOH (1:15 w/v) during 6 h at 60 °C in a stainless-steel stirred tank reactor. The suspension was centrifuged in a disc plate separator (Westfalia SA 1-02-175, Delde, Germany) fed at 1.5 L/min and operated at 9,500 rpm. The resulting supernatant was acidified to pH 4 using 3 M HCl to precipitate hemicellulose A, which was further separated through centrifugation in a disc plate separator (flow rate 1.5 L/min and 9,500 rpm). The resulting supernatant was mixed with

96% ethanol to a concentration of 55% v/v ethanol and led to 4°C for 12 h to precipitate hemicellulose B. The supernatant was removed using a peristaltic pump (Perimax PM3000, Spetec, Germany) and the excess of ethanol in the precipitate was vacuum evaporated using a rotary evaporator (Rotavapor R-220 Büchi, Switzerland) set at 80 mbar, 55°C and 100 rpm. Water was added during ethanol evaporation to diminish the viscosity of the resulted extract. Finally, the extract was diluted with distilled water to 3% solids and spray dried (Spray drier 311S YAMATO Scientific Co, Japan) at a flow rate of 500 mL/h and inlet/outlet temperatures of 190 °C and 90 °C, respectively.

2.2 Breadmaking process

For breadmaking, the baker's formulation expressed in flour+starch basis was: 1.5% salt, 1% sugar, 1% dry yeast and the tested AX incorporated in different concentrations (1, 3 and 5%). Breads produced with the model flour and 0% AX were used as control. Breads were produced using two shaping models. On the first stage, breads were produced in pans using the mini-scale system reported by Garzón et al. (2017). Briefly, doughs were kneaded in a stirrer with a turbine accessory (IKA Eurostar 40, Staufen, Germany) at 100 rpm for 90 s. After kneading, 3 g of dough were set in greased glass pans (diameter, 1.8 cm; height, 3 cm) and proofed for 40 min at 35 °C and 65% relative humidity. After fermentation, 100 µL of distilled water were added to the surface of the proofed dough to avoid dough surface dryness and were baked in an oven at 130 °C for 10 min. Two batches of 10 pan breads were run for each AX concentration. The hydration selected for breads produced in pans was fixed at 95% based on previous reports (Ayala-Soto et al., 2017). Breads from all treatments were produced with fixed water absorption in order to avoid confusion with the effect of AX.

On the second stage, breads were formed by dropping bread dough. Doughs were kneaded in a stirrer with a turbine accessory (IKA Eurostar 40, Staufen, Germany) at 100 rpm for 90 s. After kneading, 3 g of dough were dropped from a spatula onto a baking tray covered with baking wax paper. Proofing was performed during 40 min at 35°C and 65% relative humidity followed by baking at 130°C for 10 min. Two batches of 10 drop breads were run for each AX concentration and 80% hydration. The hydration was selected based on the maximum amount of water that could be added to the control model flour (0% AX) to produce a dough-drop formed bread with the adequate height to obtain samples for the texture analyses.

After determination of the best AX level required to improve the bread structure, based on the textural, morphogeometrical and crumb structure characteristics of breads, the effect of the hydration level in drop breads was evaluated. Increasing values ranging from 70% to 85% were tested in formulations containing 0% and the selected AX level based on better performance. Two batches of breads were run for each hydration level at each AX concentration.

2.3 Bread characterization

Breads were characterized regarding texture and crumb structure. The texture parameters were determined in a Texture Analyzer TAXT2i (Stable Micro Systems, Surrey, UK) using a texture profile analysis (TPA) double compression test. Slices were compressed to 50% of their original height at a test speed of 1 mm s⁻¹. When breads were produced in pans, the slices were 10 mm thick and analyzed with a cylindrical stainless-steel probe of 25 mm diameter. For drop breads, slice dimensions were 10 mm height x 10 mm width x 5 mm thick and were analyzed with a cylindrical ebonite probe of 10 mm diameter. The textural

profile parameters evaluated were hardness, springiness, cohesiveness, and resilience. In both cases, texture was assayed at least in four slices of each batch. The morphogeometry and crumb cell structure of breads were evaluated by digital image analysis. For the analysis, four breads of each formulation were selected and cut with a scalpel to obtain longitudinal section images captured at 1200 ppi using a flatbed scanner HP Scanjet G3110 (Hewlett-Packard, USA). A 10x10 mm field of view was evaluated for each image, using the Image J software (National Institutes of Health, Bethesda, MD, USA) following the method described by Garzón et al. (2018). To characterize the morphogeometry, the 2D area and height of breads were determined. Data derived from the crumb structure analysis included: cell density (μ/cm^2), surface porosity (%) and mean cell area (mm^2).

2.4 Scanning electron microscopy (SEM) of dough and bread

Fermented dough and bread samples were frozen in liquid nitrogen immediately after production and then freeze-dried. Doughs and breads were fractured and placed on a metal stub and sputter-coated with gold and palladium by ion sputter (Bio-Rad SC-500, Aname, Madrid, Spain). Sample images were recorded with a Hitachi S-4800 (Ibaraki, Japan) scanning electron microscope and observed at 10 kV accelerating voltage with magnification level of 300x or 1500x for doughs and breads, respectively.

2.5 Statistical analysis

Results were statistically analyzed by analysis of variance (ANOVA). Means were compared using Fisher's test. Analyses were performed using the Minitab 17 statistical software and 95% confidence.

3. Results and discussion

3.1 Effect of the arabinoxylans level in gluten-free pan breads

Initially, GF pan breads were made for the selection of the level of AXs to be added. For that purpose, fixed water hydration (95%) was used for the breadmaking, based on previous studies (Ayala-Soto et al., 2017). The textural characterizations of pan breads are summarized in Table 1. Hardness of breads was not significantly affected with the presence of AX, neither at the higher level tested (5%) (Table 1). Several authors have reported that the addition of AXs reduced the hardness of breads even when added at low concentrations (Ayala-Soto et al., 2017; Buksa, 2016; Buksa et al., 2013). Considering the importance of water absorption in the systems containing AX (Buksa and Krystyjan, 2019), which is even more crucial in GF, presumably, water hydration was responsible of the limited expansion and in consequence the low crumb aeration. In fact, the improvement in the hardness of GF breads due to the higher dough hydration has been previously reported (De La Hera et al., 2014). Regarding the AX role, some authors related lower crumb hardness in AX containing breads with their higher moisture content (Ayala-Soto et al., 2017; Biliaderis et al., 1995). Therefore, in those studies, the crumb softening effect could result from both the effect of the higher content of water in the formulations containing AX and its functionality as improver of the bread hardness. In contrast, in the present study water absorption was fixed in all treatments, explaining the discrepancy with other studies.

When other textural parameters were evaluated, control breads presented better performance in springiness, cohesiveness and resilience compared to those containing AX (Table 1). Although these textural parameters have not been reported in breads containing AX, they have been useful in other studies aimed to compare the impact of hydrocolloids.

Marco and Rosell (2008) found an improvement in springiness, cohesiveness and resilience when the hydrocolloid HPMC was used to make rice GF breads. Contrary, Bourekoua et al. (2018) found a negative effect in springiness when gum arabic was incorporated in GF breads, selecting low concentrations (1.5%) to improve the elasticity of breads. In the present study, control breads presented higher values of chewiness compared to the AX counterparts (Table 1), which resulted from higher springiness and cohesiveness compared to those in the AX breads.

Due to the discrepancies found in the hardness values with reported ones and the incapacity to compare the other textural features obtained herein with previous reports which assessed the role of AX in bread formulations, the effect of this hydrocolloid in the model system could not be reliably concluded. A second shaping-model was developed in order to evaluate the potential of AX as structuring agent.

3.2 Effect of arabinoxylans level in gluten-free drop breads

In the second shaping model, the addition of AX together with the lower water content of doughs, in comparison to that used for the production of pan breads, incremented the consistency giving doughs instead of batters. SEM observation of the inner structure of those doughs (Figure 1) revealed a more structured matrix with increasing levels of AX. An uneven dough matrix was observed with the presence of 1% AX, without picturing any network. The microstructure changed completely with the addition of 3% AX, distinguishing a more uniform network that hold matrix constituents and it became more open when adding 5% AX. The micrographs confirmed the holding or structuring functionality of AX at dough level that resulted from the AX-starch-proteins interactions (Bukša and Krystýjan, 2019). The consistency of these doughs allowed shaping breads by

dropping dough without the need of a physical container. Again, fixed hydration (80%) was used to link the differences among treatments only with the effect of the AX.

The characterization of drop breads in terms of texture, morphology and crumb structure is summarized in Table 2. The addition of AX affected the texture of drop breads. The hardness values decreased as the AX level increased, leading to the lowest value when breads were produced with 5% AX. This is consistent with previous reports where lower hardness values were observed in breads produced with the highest level of AX (Ayala-Soto et al., 2017; Biliaderis et al., 1995; Buksa et al., 2013; Buksa, 2016) and also with the more open structure observed in the SEM micrographs (Figure 1). The addition of AX also decreased the cohesiveness and chewiness, suggesting low internal cohesion with tendency to crumble (Matos and Rosell, 2012). Buksa and Krystyjan (2019) suggested that during baking AX and their complexes break down, which might be responsible of the cohesiveness reduction. The lower chewiness observed in breads containing AX was mainly related to the lower hardness values obtained for these breads, compared to the control bread. The addition of AX led to a reduction in the springiness of breads containing 3% and 5% AX, indicating lower stress recovery of the crumbs between compressions (Matos and Rosell, 2012). Likewise, the instantaneous recovery after the first compression of bread or resilience was negatively affected by AX. According to Matos and Rosell (2012), resilience is positively related to cohesiveness in GF breads, thus this was consistent with the results obtained for drop breads (Table 2). The detrimental effect observed in general after the addition of AX in bread formulations, could be the result of the interactions among AX and other macromolecules as has been stated in previous reports for other hydrocolloids. Biliaderis et al. (1997) proposed that some hydrocolloids may distribute in the starch intergranular spaces, reducing the interparticle contacts and thus

causing inefficient particle packing, weakening the starch structure. Also, Döring et al. (2017) used a model rye dough to prove that arabinoxylans surround the proteins affecting negatively the protein networking. In fact, that behavior could also been related to the lowering in crumb hardness observed in the AX breads (Table 2).

When textural results from both shaping models were compared, the better performance of control breads in terms of springiness, cohesiveness, chewiness and resilience was consistent (Table 1 and Table 2). However, the second model was more sensitive to detect hardness differences between the different AX levels despite the lower hydration used for this model.

When the morphogeometric characteristics were evaluated, breads produced with AX presented higher 2D areas and heights, which were significantly different at levels higher than 1% AX (Table 2, Figure 1). These results were associated to the interactions of AX with water, which according to other authors lead to an increment of the system viscosity and to higher stability of the dough foam structure, preventing collapse during baking (Ayala-Soto et al., 2017; Buksa et al., 2013; Courtin and Delcour, 2002). In fact, a deeper analysis of the crumb structure using SEM (Figure 1) confirmed a more open structure in the presence of 5% AX with numerous voids within the crumb. Likewise, crumb containing 1% AX displayed more abundant almost intact starch granules, whereas at 3% AX more extent starch gelatinization was observed, giving smoother gel structure covering rounded remnant starch granules. The presence of 5% AX led to greater gelatinization with more internal fragmentation owing the breakdown of AX-starch-protein complexes. Buksa and Krystyjan (2019) reported the release of water, after disruption of the AX complexes, which contributed to starch pasting during baking, which agree with the presence of a glossy gel covering the remaining structures.

Breads containing AX presented higher cell density compared to control breads (Table 2). The maximum number of cells per cm² was observed in the 5% AX breads. Also, the percentage of surface porosity was higher when breads contained 3% and 5% AX. Other authors have recognized the positive effect of AX in the crumb structure, however their conclusions were obtained indirectly based on improvements in bread volume and texture or determined visually (Ayala-Soto et al., 2017; Buksa et al., 2013; Buksa, 2016). Ayala-Soto et al. (2017) observed the formation of uniform crumb cells in GF breads produced with AX, especially in those with the highest level. These authors also observed that larger cells were produced in breads containing 3% AX, in comparison to those with 1% and 5%. However, in the present study the mean cell area did not show significant differences at these AX levels (Table 2).

Based on the overall results, the addition of AX in GF bread formulations, especially at 5%, contributed to the improvement of the crumb hardness, bread morphology and crumb structural characteristics of GF.

3.3 Effect of hydration in arabinoxylans drop breads

It is well documented that hydrocolloids affect the optimum hydrations of GF bread systems (Lazaridou et al., 2007; Mancebo et al., 2015; Morreale et al., 2018). Therefore, the effect of the hydration level in drop breads containing AX was evaluated (Figure 2). A concentration of 5% AX was selected due to the improved characteristics observed in previous tests (Table 2). The hydration level affected the texture parameters of drop GF breads (Table 3). For both control and AX breads, higher contents of water resulted in lower values of hardness. However, the crumb hardness of breads containing AX was significantly lower compared to their control counterparts. Moreover, in the AX breads the

differences in hardness between two hydration levels were not as significant as in the control breads (Table 3). The lowest values were observed at hydrations of 80% and 85%. Differences displayed in the SEM micrographs of the crumb structure supported texture disparities (Figure 2). SEM pictures of control breads showed a tight structure independently on the hydration level, although it was evident the increased starch gelatinization, observed as compact areas, when enhancing water levels. At low hydration, very irregular structures were observed in which compact zones were interrupted by ungelatinized starch granules detected as individual units. Only at 85% hydration, a uniform microstructure was displayed, in which ungelatinized starch granules were immersed in the glue-like matrix resulting from starch pasting and protein denaturation. Conversely, the presence of AX resulted in a number of cavities that increase with the hydration level, which might lead to more aerated crumb and in consequence lower hardness.

Results were consistent with previous reports that also associated lower crumb hardness of GF breads with higher hydration levels (Ayala-Soto et al., 2017; De La Hera et al., 2014; McCarthy et al., 2005). The lower impact observed in the absolute values of hardness of GF breads containing AX at different hydration levels was associated to the high affinity of AX to water that was partially released during baking. Same explanation has been given in previous GF breads made with HPMC (McCarthy et al., 2005). Also, the AX interactions with starch and proteins weakened the structure (Biliaderis et al., 1997; Döring et al., 2017) diminishing the hardness of breads, as has been previously mentioned when discussing crumb microstructure.

The hydration level significantly affected the springiness, cohesiveness, chewiness and resilience values in control breads (Table 3). However, for breads containing 5% AX, no

significant differences were observed in these parameters despite the hydration value. Similar to the effect observed for hardness, in general lower values for these parameters were obtained for breads containing AX compared to their unsupplemented counterparts. Again, the diminishing effect of AX in these texture parameters was associated to the interactions among AX-starch and AX-protein, that were broken during baking releasing the water molecules entrapped within them, which also contributed as plasticizer. When the morphology of breads was evaluated, increasing hydrations resulted in breads with significantly lower 2D areas and heights (Table 3, Figure 2). Since the shape of breads was not determined by a pan, higher water contents led to lower consistency and higher spread of the dough, decreasing the height and area of breads. Still, breads containing AX presented higher areas and heights compared to their control counterpart indicating that the contribution of AX to the system consistency was beneficial to hold the shape of no-pan GF breads. The cell density in the bread's crumb was also affected by the hydration level (Table 3). Breads produced with 80% hydration presented maximum value of cell density for both control and AX breads. Lower and higher hydrations decreased the cell density. McCarthy et al. (2005) also observed an increment in the number of cells/cm² with increased water and HPMC levels, but up to a certain level of these parameters. In the case of the higher values observed for AX breads, they could be related to the emulsifying properties of AX (Yadav and Hicks, 2015). The surface porosity and mean cell area were not affected by the hydration level (Table 3). Though, the surface porosity was higher in AX breads compared to control breads. In breads, it is desirable to obtain finer crumbs which involves obtaining more and smaller gas cells, thinner cell walls and even distribution of the bubble sizes and larger baked volumes (Dobraszczyk and Morgenstern, 2003; Schober et al., 2005). It is noteworthy that the combined results obtained for the

morphology and crumb structure for the AX breads indicate that these compounds led to obtaining more uniform and finer crumbs and are capable to retain gas in its structure during proofing and baking avoiding coalescence. From the values tested, the hydration level of 80% permitted to obtain the better results in both textural and crumb structure.

4. Conclusions

Although it is important to establish the optimum water absorption value in order to obtain the maximum quality of GF breads, working with different absorptions to test the structuring capacity of a new ingredient could be unfair and lead to confusion of the actual effect of the ingredient. In the present study, the use of fixed hydrations led to the evaluation of the effect of AX in the GF bread features in terms of texture, morphology and crumb structure. Using a model based in dropping dough was helpful to prove the potential of AX as a structuring agent and to develop GF breads baked without the assistance of pans. AX allowed to obtain softer breads, with higher volume and improved crumb structure. The characterization of the crumb structure using numerical data proved previous assumptions about the improvement of the crumb structure of GF breads by using AX. The detrimental effects caused in springiness, cohesiveness and resilience could be reversed by the combined effect of these molecules with other ingredients.

Author Contributions Statement

CRedit roles: **JER**: Conceptualization; Data curation; Formal analysis; Investigation; Roles/Writing - original draft; **RG**: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Roles/Writing - original draft; **SSS**: Funding acquisition; Validation; Writing - review & editing; **CMR**: Conceptualization; Funding acquisition; Investigation; Supervision; Validation; Writing - review & editing.

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FIGURE CAPTIONS

Fig. 1. Gluten-free doughs and breads produced by the drop model with different levels of arabinoxylan (AX). Magnification level of scanning electron micrographs were 300x and 1500x for doughs and breads, respectively.

Fig. 2. Gluten-free doughs and breads produced with 0% or 5% arabinoxylans and hydration (70%; 75%; 80% and 85%). Magnification level of scanning electron micrographs were 300x and 1500x for breads.

483 **Table 1. Effect of the arabinoxylan (AX) level in the texture parameters of gluten-free pan breads.**

AX (%)	Hardness (g)				Springiness				Cohesiveness				Chewiness (g)				Resilience			
0	131	±	11	a	0.99	±	0.02	a	0.66	±	0.09	a	87.2	±	18.6	a	0.35	±	0.05	a
1	141	±	18	a	0.87	±	0.02	b	0.53	±	0.07	b	64.8	±	15.0	b	0.25	±	0.04	b
3	126	±	22	a	0.90	±	0.06	b	0.52	±	0.05	b	58.5	±	11.7	b	0.23	±	0.04	b
5	117	±	5	a	0.82	±	0.07	b	0.52	±	0.03	b	50.5	±	5.6	b	0.21	±	0.02	b

484 AX: Arabinoxylans. Values are means and standard deviations of at least four replicates; means with different letters within the same
 485 parameter differ significantly ($P < 0.05$).

486 **Table 2. Effect of the arabinoxylan (AX) level in the texture, morphology and crumb structure of gluten-free drop breads**
487 **made with 80% hydration.**

AX level (%)	Texture																			
	Hardness (g)				Springiness				Cohesiveness				Chewiness (g)				Resilience			
0	321	±	49	a	0.54	±	0.06	a	0.44	±	0.08	a	68.4	±	15.7	a	0.20	±	0.04	a
1	279	±	49	b	0.54	±	0.06	a	0.36	±	0.08	b	48.4	±	9.2	b	0.13	±	0.02	b
3	246	±	15	b	0.40	±	0.06	b	0.34	±	0.03	b	33.7	±	5.6	c	0.12	±	0.01	b
5	199	±	24	c	0.42	±	0.09	b	0.37	±	0.06	b	32.7	±	10.2	c	0.13	±	0.02	b
AX level (%)	Morphology								Crumb structure											
	2D Area (cm ²)				Height (cm)				Cell density (u/cm ²)				Surface porosity (%)				Mean cell area (mm ²)			
0	1.84	±	0.12	b	0.87	±	0.03	b	9	±	2	c	2.37	±	0.68	c	0.90	±	0.42	a
1	1.97	±	0.05	ab	0.95	±	0.10	ab	14	±	1	b	3.58	±	0.45	bc	0.97	±	0.05	a
3	2.03	±	0.06	a	1.00	±	0.05	a	14	±	1	b	4.24	±	0.47	ab	1.03	±	0.11	a
5	2.03	±	0.10	a	1.02	±	0.05	a	21	±	1	a	5.48	±	1.60	a	0.82	±	0.09	a

488 AX: Arabinoxylans. Values are means and standard deviations of at least four replicates; means with different letters within the same
489 parameter differ significantly ($P < 0.05$).

490 **Table 3. Effect of hydration in the texture, morphology and crumb structure of gluten-free drop breads with 0% and 5%**
491 **arabinoxylans (AX).**

AX level (%)	Hydration (%)	Texture parameters																			
		Hardness (g)				Springiness				Cohesiveness				Chewiness (g)				Resilience			
0	70	904	±	108	a	0.48	±	0.04	bc	0.32	±	0.04	c	139.0	±	32.3	a	0.14	±	0.02	b
	75	629	±	156	b	0.64	±	0.12	a	0.40	±	0.07	ab	167.9	±	70.8	a	0.18	±	0.04	a
	80	321	±	49	c	0.54	±	0.06	b	0.44	±	0.08	a	68.4	±	15.7	b	0.20	±	0.04	a
	85	ND				ND				ND				ND				ND			
5	70	312	±	40	c	0.38	±	0.06	d	0.33	±	0.02	c	39.5	±	9.6	bc	0.11	±	0.01	c
	75	277	±	50	cd	0.40	±	0.06	d	0.37	±	0.04	bc	41.7	±	15.9	bc	0.13	±	0.02	bc
	80	199	±	24	de	0.42	±	0.09	cd	0.37	±	0.06	bc	32.7	±	10.2	bc	0.13	±	0.02	bc
	85	192	±	13	e	0.38	±	0.05	d	0.36	±	0.02	bc	26.4	±	4.9	c	0.13	±	0.01	bc
<i>P-value</i>	AX level	0.000				0.000				0.044				0.000				0.000			
	Hydration (%)	0.000				0.020				0.001				0.005				0.002			

AX level (%)	Hydration (%)	Morphology								Crumb structure											
		2D Area (cm ²)				Height (cm)				Cell density (u/cm ²)				Surface porosity (%)				Mean cell area (mm ²)			
0	70	1.99	±	0.03	b	1.07	±	0.06	b	8	±	1	de	1.69	±	0.35	b	0.73	±	0.35	b
	75	1.91	±	0.12	bc	0.92	±	0.04	d	8	±	2	d	1.97	±	0.11	b	0.83	±	0.11	b
	80	1.84	±	0.12	c	0.87	±	0.03	d	9	±	2	cd	2.37	±	0.42	b	0.90	±	0.42	b
	85	1.49	±	0.04	d	0.75	±	0.06	e	5	±	1	e	1.35	±	0.34	b	0.99	±	0.34	ab

5	70	2.24 ± 0.08	a	1.17 ± 0.02	a	11 ± 2	c	5.26 ± 0.51	a	1.38 ± 0.51	a
	75	2.22 ± 0.10	a	1.15 ± 0.03	a	15 ± 2	b	4.87 ± 0.25	a	1.17 ± 0.25	ab
	80	2.03 ± 0.10	b	1.02 ± 0.05	bc	21 ± 1	a	5.48 ± 0.09	a	0.82 ± 0.09	b
	85	1.92 ± 0.09	bc	0.99 ± 0.04	c	16 ± 3	b	4.43 ± 0.30	a	1.04 ± 0.30	ab
<i>P-value</i>	AX level	0.000		0.000		0.000		0.000		0.054	
	Hydration (%)	0.000		0.000		0.001		0.136		0.687	

492 AX: Arabinoxylans. Values are means and standard deviations of at least four replicates; means with different letters within the same

493 parameter differ significantly ($P < 0.05$). ND: not detected due to the flat shape of the bread.

494

495 **Figure 1.** Impact of arabinoxylan level on the structure of doughs and breads. SEM micrographs of dough (300x) and crumb bread
 496 (1500x), besides cross section of breads with different AX concentrations. Arrows show characteristic points highlighted in text.

500 **Figure 2.** Impact of hydration level and arabinoxylan presence on both the cross section of breads and SEM micrographs of crumbs
501 (1500x). Arrows show characteristic points highlighted in text.

502