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The effect of the addition of gelatinized flour on dough rheology and quality of bread made from brown wheat flour

Ottavia Parenti*, Lorenzo Guerrini, Valentina Canuti, Giulia Angeloni, Piernicola Masella, Bruno Zanoni

Department of Agricultural, Food and Forestry Systems Management (GESAAF), University of Florence, Piazzale Delle Cascine 16, 50144, Florence, Italy

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ABSTRACT

Although brown wheat flours are healthier than refined ones, baking quality is poor. To improve the workability and quality of brown wheat flour, we tested the addition of gelatinized flour during the production of salt-free bread. Dough rheology and bread quality were investigated in two trials. The first tested the addition of three levels of water and two levels of gelatinized brown flour. Brown flour gel addition significantly affected dough rheology and bread quality. Doughs made with gel required more water. Furthermore, significant interactions between gelatinized brown flour and water content were found for bread volume and crumb hardness. The second trial tested effects of gelatinized brown flour addition in doughs prepared with optimal water content (gelatinized flour samples required more water to reach optimum levels). Dough rheology was improved with the use of gelatinized brown flour; bread samples had significantly higher volume and lower hardness and chewiness. The addition of gelatinized brown flour may represent a good strategy to improve the baking performance of brown wheat flours, notably dough rheology and bread quality. The technique does not require the addition of new ingredients and preserves the high nutritional value of brown flour.

1. Introduction

The wheat kernel consists of three main parts (the embryo or germ, the outer coating or bran, and the endosperm), which are anatomically and chemically different (Khalid, Ohm, & Simsek, 2017). Like other baked goods, the majority of bread is made from refined wheat flour. This lacks the outer layers that are rich in important nutritional elements that are beneficial to human health, such as dietary fiber, fat, antioxidant nutrients, minerals, vitamins, lignans and phenolic compounds (Khalid et al., 2017). According to Zhou, Therdthai, and Hui (2014), refined or white flour usually corresponds to 75% w/w of the whole grain, while two other categories can be distinguished based on the extraction rate and refinement properties: wholemeal and brown flour. The former corresponds to approximately 100% yield (ash content = 1.3–1.7 g/100 g dry matter) and is made from the whole grain with nothing added or taken away. Brown flour usually contains about the 85% of the original grain (maximum ash content = 0.95 g/100 g dm) as some of the bran and germ is removed.

Epidemiological studies show that including whole grains and cereal fiber in the diet protects from chronic diseases such as cardiovascular disease, type 2 diabetes and various types of cancer; it also may improve weight regulation (Ye, Chacko, Chou, Kugizaki, & Liu, 2012).

Despite the health benefits of whole grain cereal products, consumption remains much lower than that of refined products in several countries (Rosa-Sibakov, Poutanen, & Micard, 2015). The barriers to increasing consumption of unrefined grain products include consumer taste preferences, the inability to identify unrefined grain foods, the difficulty of substituting unrefined grains for existing ingredients in meals, availability, and price (Kuznesof et al., 2012). Furthermore, the storage of wholemeal and brown flour remains problematic; shelf life is shorter than that of white flour due to lipid and lipase degradation (Doblado-Maldonado, Pike, Sweley, & Rose, 2012). Moreover, the bran in these flours has a negative impact on the viscoelastic properties of dough, and bread made from unrefined wheat flour may have low loaf volume, a dense crumb structure, and a grainy, nutty, and bitter flavor (Zhang & Moore, 1997). The literature has linked several of these phenomena to the poor technological characteristics of unrefined flour. Scanning electron microscope images of whole wheat bread showed that bran components disrupt the gluten matrix (Gan, Ellis, Vaughan, & Galliard, 1989), reducing the ability of gluten to maintain the loaf structure during fermentation and baking. Rosell, Santos, and Collar

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* Corresponding author.
E-mail address: ottavia.parenti@unifi.it (O. Parenti).

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(2010) found that fibers compete for water with other polymers, decreasing the dough's viscoelastic properties and weakening them.

Given the high nutritional value of unrefined grain, various studies have sought to optimize quality parameters of whole wheat and brown bread (Hung, Maeda, & Morita, 2006). Modified starches have been developed to limit some of the undesirable properties of native starches (Abbas, Khalil & Meor Hussin, 2010). Physical, chemical, and enzymatic treatments have been applied to obtain a huge range of starch applications, notably in the food industry (Abbas, Khalil & Meor Hussin, 2010). Starch is the major component in breadmaking, and plays an important role in the texture and quality of both the dough and bread (Abbas, Khalil & Meor Hussin, 2010).

Pre-gelatinization is a simple, physical way to modify starch. Heating starch to gelatinization temperature in the presence of a sufficient amount of water causes an irreversible molecular change. Its semi-crystalline structure transitions to an amorphous state, namely starch paste or gel (Goesaert et al., 2005). Starch gels from different sources may have an important role in improving dough and bread characteristics (Carrillo-Navas et al., 2016; Fu, Che, Li, Wang, & Adhikari, 2016; Kim, Kwak, & Jeong, 2017; Zettel, Krämer, Hecker, & Hitzmann, 2014). Starch properties have been related to loaf volume and, in particular, the pre-gelatinization temperature (Sandstedt, 1961).

The “Yukone”, “Yudane” or “Tangzhong” (water roux) method is a Japanese breadmaking technique that produces bread with a soft and sticky texture, and a high tolerance to staling (Kim et al., 2017; Naito et al., 2005; Yamauchi et al., 2014). A part of the wheat flour (usually 5–10% of the total flour mass) is mixed with water at > 60 °C to trigger starch pre-gelatinization; the mixture is cooled to room temperature, and added to the other ingredients to obtain the dough (Naito et al., 2005). The literature suggests that the slow staling, low hardness and high cohesiveness of Yudane breads is mainly due to an increase in swollen starch which, in turn, has been related to doughs with both higher water absorption and amylase enzymatic phenomena (Yamauchi et al., 2014).

This study investigated the effects of gelatinized brown flour (GBF) from wheat, prepared using the water roux method on doughs and breads. The aim was to improve dough processing and bread characteristics, thereby promoting the consumption of healthier foods and the intake of dietary fibers.

2. Materials and methods

2.1. Materials

Experimental trials were carried out with brown wheat flour (cv. *Bologna*), which can be considered as type 2 according to Italian flour classification legislation (i.e. approx. 85% of extraction yield, maximum ash content = 0.95 g/100 g dm). The flour was processed with a stone grinding mill and a sieve (two consecutive passages through a 1,100–1,200 μm sieve) at the Molino Paciscopi (Montespertoli, Florence, Italy). Two batches of Bologna brown flour from the same year and geographical area (Montespertoli, Florence, Italy) were used in the two trials; their composition is reported in Table 1.

Table 1

T1 and *T2* brown flour composition.

Trial	Flour	Starch (%)	Protein (g/100 g)	Fiber (g/100 g)	Ash (g/100 g)	Moisture (%)
T1	batch 1	64.2	10.88	6.5	0.6	14.4
T2	batch 2	62.3	11.01	8.8	0.8	15.0

2.1.1. First trial (T1): bread doughs with different water content, with or without pre-gelatinized starch

This trial was carried out on dough recipes with three different levels of water (59%, 70% and 80% w/w total mass of flour) and two levels of GBF: (i) a control sample without GBF (*T1-0%*); and (ii) 6% GBF (*T1-6%*). GBF was expressed as the percentage weight of the flour that was used to prepare it with respect to the total mass of flour. Dough moisture content corresponded to (water weight)/(total dough mass)* 100. The mass balance of dough recipes is shown in Table 2.

The baking process was standardized, and is reported below. Rheological analyses of doughs were carried out using Farinograph (Brabender, Duisburg, Germany) and Alveograph (Chopin technologies, Villeneuve-la-Garenne, France). Bread quality was evaluated both immediately after baking, and 48 h after baking. Bread volume, bread specific volume, crumb and crust moisture, and instrumental bread texture were measured.

2.1.2. Second trial (T2): bread doughs at a reference consistency with or without GBF

The same levels of GBF (i.e. 0 and 6%) used in *T1* were tested again, but this time dough samples were prepared using the amount of water required to reach the reference farinograph consistency of 500 Brabender Units (BU). Baking, dough rheological analyses, and bread quality evaluation followed the method described in *T1*; in addition, crumb specific volume (mL/g) was determined.

2.2. Preparation methods

2.2.1. GBF processing

GBF was prepared following Kim et al. (2017), namely with a 1:4 ratio of brown flour to mineral water (Levissima, Bormio, Italy). The mixture was continuously stirred as it was heated to 85 °C. This temperature was maintained for 3 min to complete starch gelatinization. Temperature was measured with a Type J penetration probe (Testo, Lenzkirch, Germany). GBF was cooled to room temperature and stored at 4 °C; it was used in experimental trials 1 d after gelatinization.

2.2.2. Bread making

The straight dough method was applied. Mixing of ingredients, dough formation, resting, leavening with fresh brewer's yeast (Lievital, Trecasali, Italy), and baking were all carried out with a bread machine (Pain dorè, Moulinex, Ecully, France). Baking temperature profiles were measured using a Type J thermocouple (diameter 1 mm, RdF, Hudson, New Hampshire) connected to an automatic data acquisition and recording system (Datascan 7220, Newbury, UK) interfaced to a computer. After baking, bread samples were cooled to room temperature and stored in paper bags.

2.3. Measurement methods

2.3.1. Brown flour composition

Flour moisture (AACC 44–15.02), starch (M24.14.01), protein (ISTISAN 1996/34, N x 6.25), total dietary fiber (AOAC 985.29) and ash (ISTISAN 1996/34) were measured according to AACC International Approved Methods.

2.3.2. Rheological analysis

Dough rheology was measured using both a Brabender Farinograph and a Chopin Alveograph. In *T1*, the farinograph test was performed in duplicate to determine dough consistency (BU) for the three amounts of added water, with and without GBF. In *T2*, the same test was carried out in duplicate following the international standard method (AACC No. 54-21) to determine the amount of water necessary to obtain dough samples with a reference consistency of 500BU with or without GBF.

The alveograph test was carried out in five replicates for both *T1* and *T2* following the AACC Method 54-30A (AACC, 2000), with some

Table 2
Dough recipes for *T1* and *T2*.

Sample	Water addition (%)	Total flour (g)	Total water (g)	Flour for GBF (g)	Water for GBF (g)	Total GBF (g)	Added flour (g)	Added water (g)	Yeast (g)	Dough (g)	Flour moisture content (%)	Yeast moisture content (%)	Dough moisture content (%)
T1-0%	58.9	310	183	-	-	-	310	182	13	505	14.4	66.5	46.6
T1-0%	70.0	310	217	-	-	-	310	217	13	540	14.4	66.5	50.0
T1-0%	80.0	310	248	-	-	-	310	248	13	571	14.4	66.5	52.8
T1-6%	58.9	310	183	18.6	74.4	93.0	291	108	13	505	14.4	66.5	46.6
T1-6%	70.0	310	217	18.6	74.4	93.0	291	143	13	540	14.4	66.5	50.0
T1-6%	80.0	310	248	18.6	74.4	93.0	291	174	13	571	14.4	66.5	52.8
T2-0%	61.0	310	189	-	-	-	310	189	13	512	15.0	66.5	47.7
T2-6%	64.5	310	200	18.6	74.4	93.0	291	126	13	523	15.0	66.5	48.8

modifications. To predict dough performance during the baking process, doughs were prepared in the alveographic mixer following planned recipes (Table 2). Therefore, the amount of brown flour was constant, and corresponded to the value given in the standard method: 250 g for each sample. However, the amount of water added to the doughs did not correspond to the standard method, but was consistent with the % water content (w/w total mass of flour in the recipe) of *T1* and *T2* recipes (Table 2).

For all samples the following parameters were measured: (i) dough tenacity (*P*; mm H_2O); (ii) dough extensibility (*L*; mm); (iii) the ratio *P/L*; (iv) flour strength ("*W*"; 10^{-4} J); and (v) the swelling index (*G*; mm).

2.3.3. Bread quality measurement

Bread volume (L) was measured using the standard millet displacement method (AACC, 2000). Specific volume (mL/g) was determined as the ratio between total volume and mass. Crumb specific volume (mL/g) was determined by cutting a small piece of crumb (5–10 g) and determining the ratio between its volume (mL) (determined using the standard millet displacement method (AACC, 2000) and its mass (g). Crumb and crust moisture (g/100 g) were measured by gravimetry at 105 °C until constant weights were reached.

The Texture Profile Analysis (TPA) of bread samples was carried out by two-bite compression using a Texture Analyzer (Stable Micro Systems, UK), equipped with a circular flat-plate probe (diameter: 30 mm), according to the procedure described in Kim et al. (2017). Hardness (N), cohesiveness, gumminess (N), chewiness (N*mm) and springiness (mm) were measured for both trials. The TPA test was carried out on three slices (1.5 cm thickness) of each bread sample in five replicates.

2.3.4. Data processing

T1 followed a full factorial experimental design with three replicates. Tested factors were GBF at two experimental levels (0% and 6%), and water amount at three experimental levels (59%, 70% and 80%). A two-way ANOVA was performed to assess significant ($p < 0.05$) differences due to these factors and their interaction. To assess differences due to bread staling, a three-way ANOVA was performed on parameters measured immediately, and 48 h after baking. In both cases, the Tukey HSD test was used as the post-hoc test.

T2 consisted of five replicates that compared the characteristics of doughs and breads at the reference consistency of 500BU. A *t*-test was performed to assess differences between mean values of the measured parameters. A two-way ANOVA was performed to assess significant ($p < 0.05$) differences due to storage time, GBF, and their interaction. The Tukey HSD test was used as the post-hoc test.

3. Results and discussion

3.1. *T1: bread dough with different water content, with or without GBF*

Table 2 shows the mass balances of dough recipes. The 6% level of GBF was determined following preliminary tests in which 3%, 6%, 9% and 12% levels were applied (data not shown). Rheological test on doughs (specifically "*W*" and *P/L* alveographic parameters) and bread quality measurements (bread volume and bread hardness) revealed that 6% was the proper GBF amount to use to optimize the baking performance.

Recipes were designed to maintain the same dough amount and moisture content between samples with or without GBF, given flour and yeast moisture content. The three levels of water addition (58.9%, 70% and 80%) were chosen to produce a broad range of dough consistencies, then to study the effects of both water content and GBF on dough and bread samples. The above levels correspond to an effective dough moisture content (DMC, water weight/total dough mass*100) of 46.6%, 50% and 52.8%, respectively.

3.1.1. Dough rheology

Fig. 2 shows the dough consistency of samples. Both water levels and GBF greatly affected consistency, which decreased as the water content increased. Moreover, BU for all samples containing 6% GBF was significantly higher than for samples without GBF ($p = 0.036$). In particular, *T1-0%* samples ranged from 560 BU for the least hydrated sample, to 100 BU for the most. A similar trend was observed for *T1-6%* samples, but consistency values were higher (ranging from 620 BU to 150 BU as DMC increased from 46.6% to 52.8%).

Alveograph parameters are important to predict baking performance, as the alveograph test causes deformations that are similar to those that occur during dough leavening and baking (Zhou et al., 2014). Fig. 3 shows *W* and *P/L* values; these parameters are the best predictors of breadmaking performance. A high *W* is associated with a good bake, and the ratio between dough tenacity and elasticity (*P/L*) has to be well-balanced. For refined flours, the optimal reference is 0.4–0.7 (Quaglia, 1984). In unrefined flour *P/L* values are usually higher (Cappelli et al., 2018; Parenti et al., 2013). Hence, to improve the baking performance of unrefined flours, it is necessary to minimize the *P/L* parameter.

Both the water level ($p < 0.001$) and starch gel ($p < 0.001$) affected significantly flour strength (*W*), which decreased as DMC increased (Fig. 3). DMC was highest in samples with the lowest strength. Moreover, *W* was highest in dough containing GBF. In particular, *W* for *T1-0%* samples was approximately 81 10^{-4} J for the lowest DMC, and 44 10^{-4} J at 50% DMC. In comparison, *W* for *T1 − 6%* samples was approximately 88 10^{-4} J for the lowest DMC, and 67 10^{-4} J at 50% DMC. At 52.8% (the highest DMC studied) the dough of *T1-0%* samples did not properly develop, and it was neither workable nor measurable. On the other hand, it was possible to obtain and measure *T1-6%* samples. In this case, *W* was approximately 23 10^{-4} J. This demonstrates that adding GBF significantly increased dough strength ($p < 0.001$).

The GBF –DMC interaction showed a significant ($p = 0.009$) effect of the experimental *P/L* values. An increase in DMC significantly reduced *P/L* in both *T1-0%* and *T1-6%* samples. GBF also significantly influenced *P/L*, which was higher than *T1-0%* samples for each DMC investigated. *P/L* for *T1-0%* samples was approximately 2.2 at 46.6% DMC, and approximately 0.4 at 50% DMC; GBF samples started from approximately 2.8 for the least hydrated sample, decreasing to approximately 1.4 *P/L* at 50%. As noted above, at the highest studied DMC (52.8%) the dough of the *T1-0%* samples could not be prepared, while a *P/L* of approximately 1 was measured for *T1-6%* samples. Hence, to optimize (i.e. minimize) *P/L*, different water contents were required for *T1-0%* and *T1-6%*.

These rheological results confirm the well-known importance of water content for good dough development, notably gluten network formation (Zhou et al., 2014), and they demonstrate that GBF had a marked effect on dough consistency. It is also important to point out that dough rheology was strongly affected by a narrow range (46.6–52.8%) of water content (Table 2).

The mechanisms that govern how water content influences dough rheology are related to the molecular mobility of water (Blanshard, Frazier, & Galliard, 1985). The addition of GBF may influence water distribution in the dough. At room temperature, starch granules are able to absorb water up to about 50% of their dry weight, but the gelatinization process increases this through granule swelling and the loss of crystallinity and molecular order (Goesaert et al., 2005). Consequently, in GBF enriched samples, water binding to starch molecules could mean that there is less available for dough development; at the same moisture level, GBF doughs had higher consistency than *T1-0%* samples. Hence, in the presence of pre-gelatinized starch, the same dough consistency could be obtained with more water.

Alveograph data clarified the influence of water content and GBF on the dough's physical and mechanical properties. A certain amount of water is essential for protein hydration, which optimizes gluten network development and creates a perfect balance between tenacity, elasticity and extensibility (Zhou et al., 2014). The experimental *W* and *P/L* values that were observed as a function of water content could be consistent with the above phenomena. The addition of GBF significantly increased *P/L*, and this could be due to an increase in tenacity (i.e. *P*) and/or a decrease in extensibility (i.e. *L*). The gelatinization process could be responsible for making water less available for gluten hydration (Blanshard et al., 1985).

3.1.2. Bread quality

Table 3 shows quality characteristics of bread samples. Water content exercised a significant effect on crumb moisture, cohesiveness and springiness. Crumb moisture clearly increased as water content increased, and higher DMC was consistent with higher crumb moisture. Cohesiveness refers to how well the product withstands a second deformation relative to its resistance under the first deformation. This also increased as a function of water content; an increase of approximately 70% was seen as DMC increased from 46.6% to 52.8%. Furthermore, springiness increased. Springiness is an indicator of the product's elasticity (i.e. how well it physically springs back after it has been deformed during the first compression). This parameter increased by approximately 20% between samples with 46.6% and 52.8% DMC.

The addition of GBF had a significant effect on crust moisture (Table 3). Experimental data showed a decrease of approximately 10% for *T1-6%* samples compared to *T1-0%*. GBF could facilitate water mass transfer at the bread's surface; absorbed water in the starch could be more "free" than water in the development of the gluten network, leading to greater crust dehydration in the *T1-6%* samples.

Significant effects of the GBF –water interaction can be observed with respect to bread volume, and hardness (Table 3). Regarding bread volume, at 46.6% DMC, bread volumes of *T1 − 0%* samples were significantly higher than *T1 − 6%* samples. At 50% DMC, a significant increase in bread volume was observed in all samples, compared to 46.6%. However, at 52.8% DMC, the volume of *T1-0%* samples fell (to 1.32 L), while *T1 − 6%* samples reached their highest value (1.4 L). Therefore, maximum bread volume occurred at 50% DMC in *T1-0%* samples and at 52.8% DMC in *T1-6%* samples. With respect to crumb hardness, in *T1-0%* samples this parameter was lower at 50% DMC than at 46.6%. On the other hand, it increased at 52.8% DMC to a value higher than at 46.6 (5.1 compared to 3.4), indicating a non-linear trend. *T1-6%* samples differed, as hardness decreased linearly as water content increased. In this case, samples were hardest (8 N) at 46.6% DMC; this decreased to 5.8 N at 50% DMC, reaching 3 N at 52.8% DMC. T1-0% and T1-6% different trends, with regard to bread volume and hardness, revealed that they had different water requirements. Specifically, a DMC around 50% could optimize T1-0% bread quality (i.e. highest volume, lowest hardness), while higher water content was necessary to optimize T1-6% sample. Hence, GBF addiction significantly changed (i.e. enhanced) the optimum water amount of bread doughs.

These results are consistent with literature (Kim et al., 2017; Yamauchi et al., 2014; Zettel et al., 2014). Kim et al. (2017) reported a decrease in hardness in rice bread samples prepared with GBF. Yamauchi et al. (2014) observed that bread samples containing GBF were softer than control ones.

The above quality characteristics were compared with those for samples stored for 48 h at room temperature. The only significant difference was found for crumb hardness with respect to *T1 − 0%* samples. In this case, at 46.6% DMC crumb hardness increased from 3.4 ± 0.3 to 5 ± 1; at 50% it increased from 2.4 ± 0.1 to 4.9 ± 0.2, and at 52.8% DMC it increased from 5.1 ± 0.4 to 6.4 ± 0.8. No significant differences were found for *T1-6%* samples. Therefore, the addition of GBF also reduced staling, and helped to preserve bread softness during shelf-life.

Overall, the results of *T1* demonstrated a significant effect of GBF on both dough rheology and bread volume and texture. This effect was

Table 3
Quality characteristics of T1 bread.

Parameter	*T1-0%* samples			*T1-6%* samples			*P GBF*	*P H_2O*	*P GBF*H_2O*
	46.6% *DMC*	50% *DMC*	52.8% *DMC*	46.6% *DMC*	50% *DMC*	52.8% *DMC*			
Bread volume (L)	1.33 ± 0.07	1.4 ± 0.2	1.32 ± 0.04	1.21 ± 0.05	1.30 ± 0.09	1.4 ± 0.2	ns	ns	*
Bread specific volume (L/kg)	3.31 ± 0.16	3.27 ± 0.24	2.95 ± 0.09	3.00 ± 0.11	3.01 ± 0.20	3.13 ± 0.36	ns	ns	ns
Crumb moisture (g/100 g)	44.8 ± 0.6^{x}	49.3 ± 0.2^{y}	52.2 ± 0.1^{z}	45.1 ± 0.5^{x}	49.6 ± 0.2^{y}	52.2 ± 0.2^{z}	ns	***	ns
Crust moisture (g/100 g)	27 ± 3^{a}	26.1 ± 0.8^{a}	28.9 ± 0.4^{a}	23.2 ± 0.6^{b}	25.4 ± 0.3^{b}	26.3 ± 0.3^{b}	*	ns	ns
Hardness (N)	3.4 ± 0.3^{a}	2.4 ± 0.1^{a}	5.1 ± 0.4^{a}	8 ± 1^{b}	5.8 ± 0.6^{b}	3 ± 1^{b}	**	ns	**
Hardness (N) 48 h	5.2 ± 1.1	4.9 ± 0.2	6.4 ± 0.8	14.4 ± 7.4	4.6 ± 0.3	4.4 ± 0.3	ns	ns	***
Cohesiveness	0.24 ± 0.03^{x}	$0.34 \pm 0.01^{x,y}$	0.41 ± 0.06^{y}	0.27 ± 0.02^{x}	$0.33 \pm 0.05^{x,y}$	0.46 ± 0.08^{y}	ns	*	ns
Springiness (mm)	0.72 ± 0.06^{x}	$0.83 \pm 0.10^{x,y}$	0.92 ± 0.02^{y}	0.75 ± 0.03^{x}	$0.83 \pm 0.06^{x,y}$	0.91 ± 0.02^{y}	ns	**	ns
Chewiness (N mm)	0.58 ± 0.07	0.81 ± 0.17	1.91 ± 0.26	1.50 ± 0.24	1.60 ± 0.33	1.36 ± 0.37	ns	ns	ns

Data are expressed as mean ± SE. DMC is dough moisture content (water weight/total dough mass*100). P GBF, P H_2O and P GBF * H_2O refer to the effects of these factors: GBF, water and their interactions GBF*water. *, ** and *** indicate significant differences at $p < 0.05$, $p < 0.01$ and $p < 0.001$, respectively; "ns" indicates no significant difference at $p < 0.05$. Means in a row with different superscripts are significantly different ($p < 0.05$); specifically, "a", and "b" refer to the GBF main effect, while "x", "y" and "z" refer to the water main effect.

directly related to DMC, suggesting that bread quality can be optimized by adjusting this parameter. The following section addresses this question.

3.2. T2: bread dough at a reference consistency, with or without GBF

The literature suggests that optimal dough consistency is 500 BU for refined flours. Other numbers have been reported for unrefined flours, due to their different composition (Zhou et al., 2014). A higher fiber content increases water absorption, and competition for hydration with protein molecules during dough development (Gómez, Ronda, Blanco, Caballero, & Apesteguía, 2003). Nevertheless, even in this case, 500 BU is typically used to determine optimal dough development (Boita et al., 2016; Khalid et al., 2017). Therefore, we compared dough rheology and bread quality between samples without GBF (*T2-0%*) and with GBF (*T2-6%)* at a dough consistency of 500 BU.

3.2.1. Dough rheology

A Farinograph test was carried out to determine the amount of water necessary to reach the reference consistency of 500 BU. This found that the *T2-0%* samples required 61% water, while the *T2-6%* samples required 64.5%. These levels correspond to 47.7% DMC for *T2-0%* dough samples and 48.8% DMC for *T2-6%* samples (Table 2). These experimental data were congruent with those obtained during the *T1* trial; *T2-6%* dough samples required more water to reach the same consistency as T1-6% sample, as GBF reduced the availability of water for dough development. No significant differences between T2-0% and T2-6% samples were found with regard to the other farinographic parameters: DDT – dough development time, 5 ± 0.5 min; DST – dough stability, 10 ± 1 min; DW – dough weakening 20 ± 5 BU.

Alveograph experimental data highlighted significant differences between *T2* samples; Fig. 4 shows flour strength (*W*), and *P/L*. Dough extensibility increased by approximately 30%: from 35 ± 3 mm for *T2-0%* samples to 46 ± 4 mm for *T2-6%* samples. A similar increase of approximately 30% was found for *W*: from 73 ± 7 10^{-4} J for *T2-0%* samples to 96 ± 5 10^{-4} J for *T1-6%* samples. On the other hand, *P/L* did not change significantly (1.4 ± 0.2 compared to 1.1 ± 0.2; $p = 0.09$). In *T2* the additional water content improved the alveograph performance of dough compared to T1. Moreover, in *T2*, *W* reached the same, maximum value observed in *T1*, while *P/L* remained low. These results suggest that the use of GBF improves baking performance, as the capacity of the dough to hold gas during the leavening step is improved, which, in turn, probably increases the volume, and softens the texture of bread.

3.2.2. Bread quality

Fig. 1 shows the baking temperature profiles of *T2-0%* and *T2-6%* samples, which were consistent with bread baking theory (Zanoni, Peri, & Pierucci, 1993). Despite the different water amount of *T2-0%* and *T2-6%* samples (61% vs 64.5%, w/w total flour mass in the recipe), no significant differences were found in the baking ramp profile.

Table 4 shows quality characteristics of bread samples immediately after baking and after 48 h of storage at room temperature.

Immediately after baking, crumb moisture content for all *T2* samples was congruent with DMC values given in Table 2. Bread volume was approximately 20% higher in *T2-6%* samples than in *T2-0%* samples. Another clear effect was found for crumb specific volume, which increased by approximately 15% for *T2-6%* samples compared to *T2-0%*. Fig. 5 shows that GBF led to more swollen and porous bread samples. These experimental data are consistent with Yamauchi et al. (2014), Zettel et al. (2014) and Kim et al. (2017), who observed that the addition of GBF caused a significant increase in bread volume. Therdthai, Zhou, and Adamczak (2002) and TSAI et al. (2012) argued that highly gelatinized dough increases bread volume by retaining more gas and water vapor in pore walls. Naito et al. (2005) suggest that increased amounts of GBF provide wall materials with stickiness and good expansion characteristics.

All texture parameters changed significantly with the addition of GBF. *T2-6%* samples were characterized by the following; lowest hardness, highest cohesiveness, and lowest springiness. In particular, hardness decreased by approximately 35% (Kim et al., 2017; Yamauchi et al., 2014; Zettel et al., 2014), while springiness decreased by approximately 50%.

Storage was associated with staling (Table 4). After 48 h, significant decreases in crumb specific volume, crust moisture and cohesiveness were found for all samples. Consistent with the literature (Zettel et al., 2014; Yamauchi et al., 2014), differences between *T2-6%* and *T2-0%* samples were preserved during storage with respect to crumb specific volume and texture parameters. On the other hand, hardness increased more in *T2-0%* samples than *T2-6%* samples. Finally, differences in springiness were observed between the samples; it decreased in *T2-0%* samples, while it increased in *T2-6%* samples, reaching values close to those of bread without GBF immediately after baking.

4. Conclusions

To the best of our knowledge, this is the first study of the effect of GBF to bread and dough made with brown flour. It is found to have several effects First, it interacts strongly with water, changing the amount of water required to make dough. The correct dose of GBF is linked to the optimal amount of water; in this trial, we chose a reference

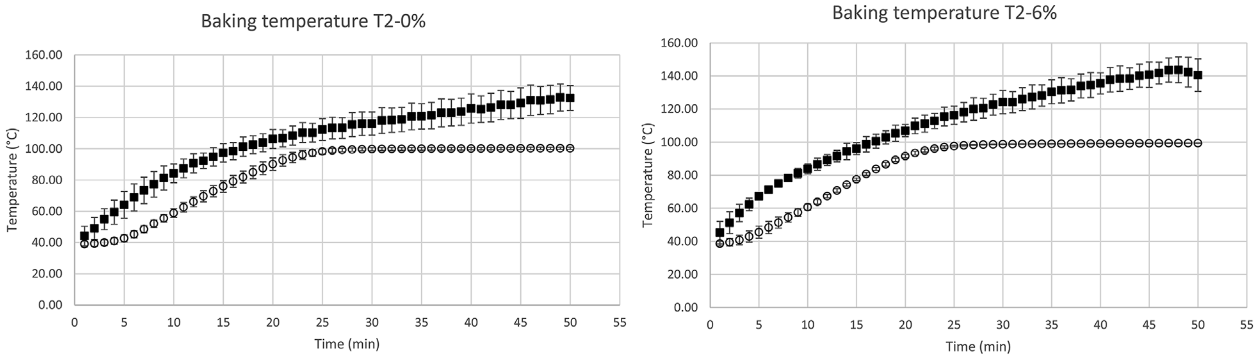

Fig. 1. Bread quality. The baking temperature profiles (Fig. 1) of the *T2-0%* and *T2-6%* samples were similar. ■– crust temperature; ○– crumb temperature. According to the bread baking theory (Zanoni et al., 1993), a higher temperature than 100 °C, which asymptotically tends towards the oven temperature, was reached at the bread's surface; then, a dehydration occurred and a dried and brown crust was formed (Table 3). At the inner bread's portion the temperature rose at low rate and asymptotically tended towards 100 °C (i.e. the evaporation-front temperature); then, a crumb was formed with a moisture content which was the same value as that of the raw dough (Table 3).

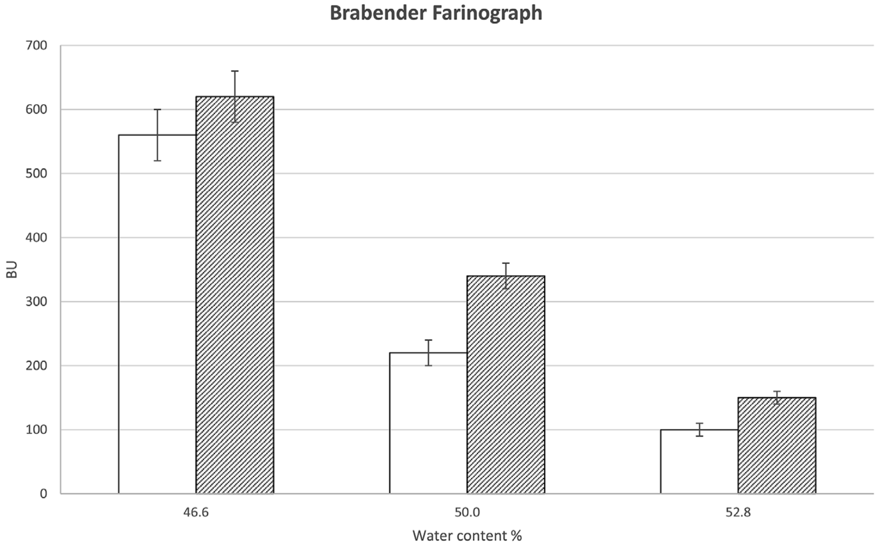

Fig. 2. Farinographic test on T1-0% and T1-6% samples at different dough moisture contents: 46.6%, 50.0%, 52.8%; □– T1-0%; ▨– T1-6%.

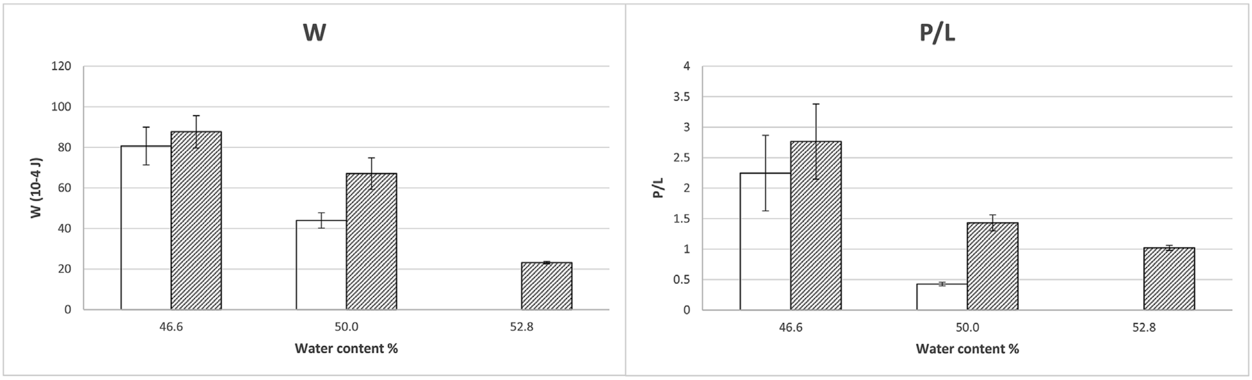

Fig. 3. Alveographic parameters "W" (J), the baking strength and P/L, the ratio between tenacity (P) and extensibility (L) of T1-0% and T1-6% samples at different dough moisture contents: 46.6%, 50.0%, 52.8%; □– T1-0%; ▨– T1-6%.

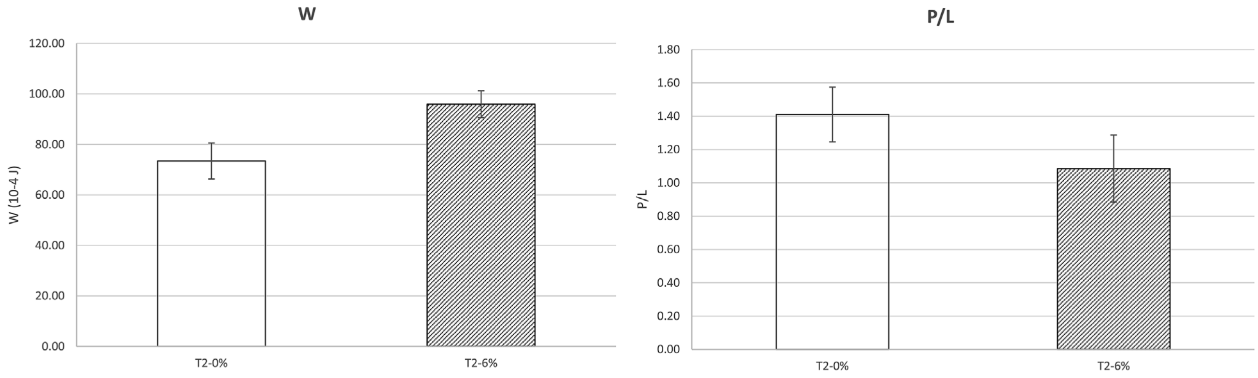

Fig. 4. Alveographic parameters: "W" (J 10-4), the baking strength, L (mm), extensibility and P/L, the ratio between tenacity (P mm H2O) and extensibility L (mm) of T2-0% and T2-6% samples at the optimal consistency value of 500BU; □– T2-0%; ▨– T2-6%.

value of 500BU. GBF significantly improved both the dough's rheological proprieties and bread quality. Better strength and tenacity/extensibility ratios were obtained with the addition of 6% GBF. Furthermore, both bread volume and texture were significantly improved. The 48 h storage test confirmed that changes due to GBF can be maintained during the bread's shelf-life. GBF technique is based on the incorporation of standard brown flour; only its form changes. As it does not involve the use of additives, the high nutritional value of the flour is preserved. Furthermore, as it produces brown breads with better quality parameters, it could be used to promote the adoption of unrefined, healthier foods.

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Table 4
Quality characteristics of T2 bread.

Parameter	*T2-0%* samples *(61% DMC)*		*T2-6%* samples *(64.5% DMC)*		*P GBF*	*P time*	*P GBF*time*
	after baking	after 48 h storage	after baking	after 48 h storage			
Bread volume (L)	1.14 ± 0.09^{a}	nd	1.35 ± 0.03^{b}	nd	**	nd	nd
Bread specific volume (L/kg)	2.61 ± 0.23^{a}	nd	3.05 ± 0.07^{b}	nd	**	nd	nd
Crumb specific volume (mL/g)	2.8 ± 0.2^{ax}	2.5 ± 0.2^{ay}	3.3 ± 0.1^{bx}	3.0 ± 0.2^{by}	***	**	ns
Crumb moisture (g/100 g)	46.4 ± 0.6^{a}	46.4 ± 0.3^{a}	47.5 ± 0.4^{b}	47 ± 1^{b}	*	ns	ns
Crust moisture (g/100 g)	23.7 ± 0.9^{x}	22.3 ± 0.6^{y}	24 ± 1^{x}	22.4 ± 0.8^{y}	ns	*	ns
Hardness (N)	7 ± 2^{a}	9 ± 3^{a}	4.6 ± 0.7^{b}	5 ± 1^{b}	**	ns	ns
Cohesiveness	0.36 ± 0.03^{ax}	0.29 ± 0.02^{ay}	0.41 ± 0.06^{bx}	0.33 ± 0.04^{by}	*	**	ns
Chewiness (N mm)	2.2 ± 0.7	1.8 ± 0.3	1.7 ± 0.5	1.3 ± 0.2	ns	ns	ns
Springiness (mm)	0.84 ± 0.05^{ax}	0.7 ± 0.1^{ay}	0.41 ± 0.06^{bx}	0.8 ± 0.1^{by}	*	*	ns

Data are expressed as mean ± SE. DMC is dough moisture content (water weight/total dough mass*100). P GBF, P time and P GBF*time refer to the effects of these independent variables (factors): GBF, time and their interactions GBF*time. *, ** and *** indicate significant differences at $p < 0.05$, $p < 0.01$ and $p < 0.001$, respectively; "ns" indicates no significant difference at $p < 0.05$. Means in a row with different superscripts are significantly different ($p < 0.05$); specifically, "a", and "b" refer to the GBF main effect, while "x", and "y" refer to the time main effect.

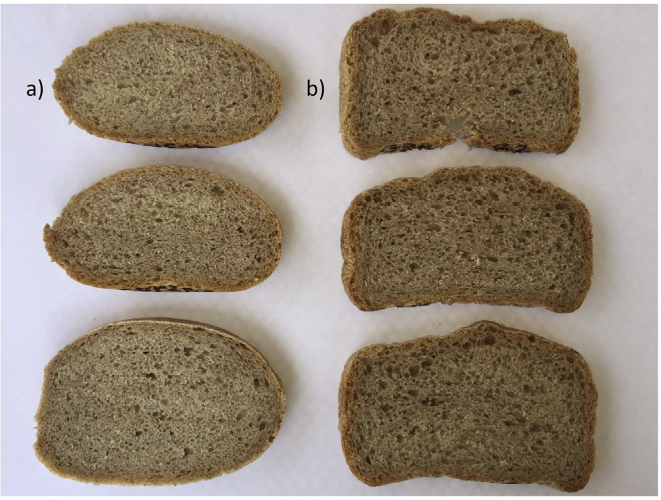

Fig. 5. Bread structure of T2-0% (a) on the left vs T2-6% (b) on the right.

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