

# Adjustment of dough hydration to achieve standardised volume in gluten-free breads

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## ABSTRACT

Although research on gluten-free breads has expanded considerably over the past decades, quality control of gluten-free flours and doughs remains challenging, and variability in loaf volume have yet to be effectively minimised. In studies on wheat breads, dough hydration is commonly adjusted to reduce the influence of dough consistency on specific loaf volume, thereby eliminating confounding effects on quality attributes such as texture and staling. However, this practice is seldom applied in gluten-free bread research. In the present study, the farinograph was proposed as a tool for both the quality assessment of flours and doughs and for adjusting formulations according to flour characteristics, with the aim of improving the consistency of loaf volume. Seven commercially available rice flours and one control were evaluated. Water absorption capacity, particle size distribution, and pasting properties were measured to assess flour heterogeneity. Both the flours and their corresponding doughs were analyzed using the farinograph, and baking trials were conducted at constant and adjusted hydration levels. Farinograph parameters proved to be reliable predictors of bread volume, showing significant correlations at the 95 % and 99 % confidence levels. Adjustment of hydration based on farinograph data successfully reduced mean volume differences from 21 % to 3 %. This methodology may enhance research on gluten-free breads. It helps mitigate the influence of variations in dough consistency and loaf volume on other bread quality attributes.

## 1. Introduction

In recent decades, there has been a marked increase in the consumption of gluten-free breads, not only among coeliac patients but also among other sectors of the population. This may be attributed to the high prevalence of individuals with non-coeliac gluten sensitivity, estimated to affect approximately 10 % of the population. Nevertheless, a substantial proportion of this group does not exhibit true gluten sensitivity. This subgroup includes individuals displaying a nocebo response to gluten products, as well as those affected by irritable bowel syndrome, which is associated with the ingestion of specific fermentable carbohydrates (FODMAPs) (Biesiekierski et al., 2025). Likewise, research on this subject has expanded considerably, and as a result, numerous reviews on the development of gluten-free breads have been published in recent years (Masure et al., 2016; Roman et al., 2019). However, one of the main challenges faced by gluten-free bread manufacturers is the lack of consistency in their products. This problem becomes more evident when raw materials change, particularly gluten-free flours and starches, which form the basis of most formulations. This issue is compounded by the

limited knowledge of how to assess the quality of these raw materials. It is also a limitation in many scientific studies, where raw materials such as rice flour or maize starch are not characterized, or only the supplier is mentioned, or at best their proximate composition is reported (Zhang et al., 2025).

Rice flour and maize starch are the most widely used ingredients for gluten-free breadmaking worldwide, both in commercial products (Roman et al., 2019) and in scientific studies (Masure et al., 2016). In the case of rice flour, it is known that factors such as particle size, rice type, and water absorption capacity strongly influence gluten-free breads, particularly in terms of loaf volume and texture (Cornejo and Rosell, 2015). However, these studies compared rice flours obtained through different processing systems that induced specific changes, rather than commercially available flours with no information about rice origin or processing.

It is well established that the water content of the formulation, and therefore dough rheology, plays a crucial role in determining bread volume (Sahagún and Gómez, 2018). In general, specific volume increases as hydration increases, up to a maximum beyond which the

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dough can no longer retain its structure and collapse, either during fermentation or in the early stages of baking. This effect is particularly relevant in doughs containing hydroxypropyl methylcellulose (HPMC), the most widely used gluten substitute in commercial gluten-free breads worldwide (Roman et al., 2019). Likewise, an increase in oil content relative to starchy materials, which reduces dough consistency, produces a similar effect to higher hydration, increasing loaf volume up to a maximum (Mancebo et al., 2017).

In most studies on gluten-free breads, hydration is either left unmodified despite changes in formulation or adjusted based on poorly defined preliminary tests. A few articles have attempted to adjust hydration according to fundamental rheological tests (Yazar, 2025) or based on the water absorption capacity of ingredients (Horstmann et al., 2018). However, no studies have demonstrated that these approaches allow correction of hydration in order to equalize the specific volume of breads produced. Indeed, in such studies, volumes are not equalized. Other works have opted to test several hydration levels for each ingredient combination to illustrate the impact of this parameter, at the cost of considerable additional work (Sahagún and Gómez, 2018).

The farinograph is a widely used instrument for controlling the quality of wheat flour worldwide. It essentially consists of a mixer in which the torque required to move the mixing blades is recorded. The amount of water required to reach a given consistency is referred to as the water absorption of the flour and is known to depend on its components. The resulting curve rises in consistency until reaching a maximum, after which it progressively declines. Both the time taken to reach the maximum (dough development time) and the rate of subsequent decline (stability) are closely related to protein quality and gluten network formation (Don, 2022).

In studies on wheat breadmaking, the farinograph or a similar device is considered almost indispensable for correcting dough hydration depending on formulation changes or ingredient modifications, due to the well-established influence of dough rheology on final bread volume (Stojceska and Butler, 2012). In the case of gluten-free starches, flours, or other ingredients, the farinograph has been used to study ingredient behavior during mixing (Lazaridou et al., 2007). However, only Ziobro et al. (2013) used it to determine the appropriate hydration level for baking in a study on protein supplementation. But no study has related this measurement to the volume of the breads obtained. Furthermore, different studies report varying optimal dough consistencies (Bresciani et al., 2022). To address difficulties in testing some gluten-free raw materials, an accessory has been developed that reduces the volume of the farinograph mixing bowl. This accessory was used by Sahin et al. (2020) to compare dough hydration adjustments based on farinograph tests and on an alternative method when testing five hydrocolloids. These authors concluded that farinograph use improves bread quality, but they did not aim to equalize bread specific volume.

The use of equipment such as the Mixolab, which also analyses dough behavior during mixing (and subsequent heating) and provides water absorption data, has become common in recent years. However, it is typically employed for dough characterization rather than to adjust hydration during baking, which is usually performed at constant hydration (Aguilar et al., 2022; García-Ramón et al., 2023). No studies have correlated such parameters with the resulting bread volume.

The working hypothesis of the present study is that farinographic analysis of gluten-free flours can identify variations in raw materials that influence the volume of the resulting breads. Moreover, dough analysis may allow hydration adjustment to reduce changes in the specific volume of breads produced with different batches of these raw materials, as already occurs in wheat breadmaking.

For this purpose, farinograph analyses were conducted on eight rice flours, both with the accessory and with the standard bowl. Doughs prepared using a gluten-free bread formulation were also analyzed, and the hydration level required to achieve the same consistency as a control was determined. Baking trials were then performed with all flours under both constant and adjusted hydration conditions, and the resulting loaf

volume and specific volume were compared with the farinographic data.

## 2. Materials and methods

### 2.1. Materials

Seven rice flours were purchased from the local market. The brands analyzed were Rex (Albalat de la Ribera, Valencia, Spain), Hacendado (produced by Molendum Ingredients, Coreses, Zamora, Spain), Don Pedro (Alcalá de los Gazules, Cádiz, Spain), Carrefour (Alcobendas, Madrid, Spain), Dacsa (Almácer, Valencia, Spain), Nomen (Deltebre, Tarragona, Spain), and Harimsa (Cartagena, Murcia, Spain). In the study, these flours are referred to as F1–F7. In addition, rice flour supplied by Dacsa Atlantic (Coruche, Portugal) was used as a control.

For the breadmaking trials, native maize starch (Roquette Laisa España S.A., Valencia, Spain), refined sunflower oil (Rafael Salgado, Oleosalgado S.A., Seville, Spain), white sugar (Acor, Valladolid, Spain), Saf-instant yeast (Lesaffre Ibérica S.A., Valladolid, Spain), hydroxypropyl methylcellulose K4M (Rettenmaier Ibérica, Barcelona, Spain), iodized salt (Hacendado, Salinas de Odiel S.L., Huelva, Spain), and local tap water were also used.

### 2.2. Characterisation of flours and starches

The rice flours were characterized in terms of moisture content, particle size, water absorption capacity, and pasting properties.

Moisture content was measured according to method AACC 44–15.02 (AACC, 2012). Flour particle size was evaluated using a Mastersizer 3000 particle size analyser (Malvern Instruments, Malvern, United Kingdom).

Water binding capacity (WBC), defined as the amount of water retained by the sample after centrifugation, was measured following method 56–30.01 (AACC, 2012) with modifications. A 1.25 g ( $\pm 0.01$  g) sample of rice flour was mixed with 25 mL of distilled water in centrifuge tubes. After 1 min of vortex homogenization (MS2 Minishaker, IKA, Staufen, Germany), the mixture was centrifuged at  $3000\times g$  for 15 min, and the supernatant was decanted into an evaporating dish. The centrifuge tube without the supernatant was weighed. WBC was expressed as the amount of water retained per gram of dry sample.

Pasting properties were studied using a Rapid Visco Analyzer (RVA, model RVA-4800, PerkinElmer España S.L., Tres Cantos, Spain). A 3.5 g ( $\pm 0.01$  g) sample (dry basis) was dispersed in 25 g ( $\pm 0.01$  g) of distilled water. The mixture was subjected to heating and cooling cycles according to AACC method 76–21.02 (AACC, 2012).

All measurements were carried out in duplicate.

### 2.3. Farinographic analysis

All rice flours and the doughs prepared with them were analyzed using a Brabender FarinoGraph (Anton Paar, Graz, Austria) equipped with the S300 measuring mixer. Separate analyses were conducted on rice flours and on doughs containing all ingredients except yeast. Both types of analysis (flour or dough) were carried out with and without the FarinoAdd-S300 accessory (Anton Paar, Graz, Austria) to assess its effectiveness. The mixer and dosing water temperatures were kept constant at  $30.0 \pm 0.2$  °C, and the mixing speed was set at 63 rpm.

For analysis with the FarinoAdd-S300 accessory, 220 g of dough (flour and water mixture, or full formulation without yeast) were used, whereas 450 g were used when the accessory was not employed. These quantities, determined in preliminary trials, allowed a wider hydration range, avoided overloads, and provided more stable and reproducible results.

The percentage of water used for flour analysis was 70 % (70 parts per 100 parts of rice flour). The same hydration level (70 parts water per 100 parts of the rice flour–maize starch mixture) was used for full dough analyses, employing the bread formulation described in section 2.4,

except for yeast. At this hydration level, the maximum consistency obtained was 103 FU, very similar to the values reported by Sahin et al. (2020).

To perform trials at adjusted hydration, water levels were modified to achieve a maximum consistency of 100 FU ( $\pm 10$  FU).

All analysis were carried out in duplicate.

#### 2.4. Breadmaking

A basic gluten-free bread formulation was selected for this study. The formulation used consisted of 50 parts rice flour, 50 parts maize starch, 6 parts sunflower oil, 5 parts sucrose, 2 parts HPMC, 2 parts dried yeast, and 2 parts salt.

To determine the appropriate hydration, a preliminary study was carried out to evaluate volume changes at different hydration levels and the farinograph results obtained for these doughs. For the subsequent study, a hydration level that produced breads with good volume and was suitable for farinograph analysis (which does not register excessively low consistencies) was selected. The chosen hydration was 70 % (70 parts water per 100 parts of the maize starch–rice flour mixture), providing a maximum consistency close to 100 FU, similar to the values reported by Sahin et al. (2020). Breads were also prepared at adjusted hydration levels (water required to achieve a maximum consistency of 100 FU) as determined by farinographic analysis.

All ingredients, except dried yeast and tap water, were mixed at speed 1 (60 rpm) for 1 min using a KitchenAid Professional mixer (KitchenAid, St. Joseph, Michigan, USA) with a dough hook (K45DH). The yeast was prehydrated in water and then incorporated into the mixture, which was kneaded at speed 2 (95 rpm) for 8 min. Portions of 150 g of dough were placed into oil-coated aluminium pans (159 × 109 × 39 mm) and fermented at 30 °C and 80 % RH for 60 min. After fermentation, the doughs were baked at 220 °C for 40 min. The aluminium pans were removed, and the breads were cooled for 60 min at room temperature before being placed in polyethylene zip-lock bags (Bosque Verde, Mercadona, Spain).

Breads were stored at 22 °C and analyzed 24 h after preparation. All bread batches were prepared in duplicate.

Bread volume was measured in three loaves per batch using a Volcan Profiler volume analyser (Stable Microsystems, Surrey, UK). Specific volume was calculated as bread volume divided by bread weight, expressed as cm<sup>3</sup>/g.

#### 2.5. Statistical analysis

Statistical analyses were performed using Statgraphics Centurion XVI software (Statpoint Technologies, Warrenton, USA). All results were subjected to analysis of variance (ANOVA) and linear regression. Fisher's least significant difference (LSD) test was applied to compare means with 95 % confidence intervals.

### 3. Results and discussion

#### 3.1. Characterisation of the flours

Table 1 shows some characterization data for the flours. Moisture content of the rice flours was very similar, ranging from 9.81 to 11.53 g 100 g<sup>-1</sup>, with the control flour only showing significant differences compared to F3, which was slightly drier. Water binding capacity (WBC) of the flours ranged from 2.26 to 2.63 g g<sup>-1</sup>, with the control being among the lowest, without significant differences compared to F5 and F7. F3 exhibited the highest WBC, which may be related to its lower moisture content. These differences are attributable to flour composition, since plant proteins absorb more water than starch (Shin et al., 2010), as well as to the amount of damaged starch, which absorbs more water than intact starch (Qin et al., 2021). They also depend on the milling process and grain hardness, as well as particle size, with smaller

**Table 1**

Moisture, hydration properties, and mean particle size (D [4,3]) of the rice flours.

	Moisture (g/100g)	WBC (g/g)	D [4,3] (μm)
Control	11.09 ± 0.20 <sup>bcd</sup>	2.27 ± 0.02 <sup>a</sup>	171.33 ± 1.53 <sup>f</sup>
F1	11.28 ± 0.16 <sup>cd</sup>	2.43 ± 0.02 <sup>d</sup>	90.27 ± 0.32 <sup>a</sup>
F2	11.53 ± 0.11 <sup>d</sup>	2.39 ± 0.03 <sup>d</sup>	125.67 ± 0.58 <sup>c</sup>
F3	9.81 ± 0.27 <sup>a</sup>	2.63 ± 0.01 <sup>e</sup>	223.67 ± 2.52 <sup>h</sup>
F4	10.59 ± 0.08 <sup>b</sup>	2.33 ± 0.05 <sup>c</sup>	165.00 ± 1.00 <sup>e</sup>
F5	10.66 ± 0.49 <sup>b</sup>	2.26 ± 0.01 <sup>a</sup>	207.00 ± 1.00 <sup>g</sup>
F6	11.02 ± 0.04 <sup>bcd</sup>	2.32 ± 0.01 <sup>bc</sup>	147.67 ± 0.58 <sup>d</sup>
F7	10.82 ± 0.70 <sup>bc</sup>	2.28 ± 0.04 <sup>ab</sup>	96.67 ± 0.71 <sup>b</sup>

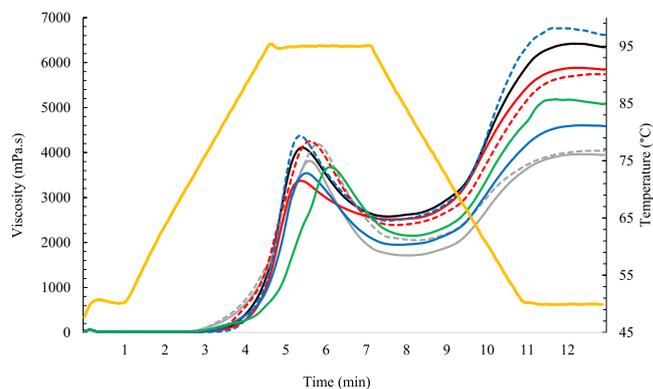
Values ± standard deviations followed by different letters indicate significant differences ( $p < 0.05$ ). WBC: water-binding capacity.

particle sizes leading to higher WBC due to the greater surface area available for absorption (Lapčková et al., 2021).

Regarding particle size, the flours displayed a wide range, with D (4,3) values ranging from 90.27 μm in F1 to 223.67 μm in F3. The control flour was among those with the highest D (4,3). These differences are likely due to flour production processes (milling and sieving) and grain hardness.

Pasting behavior (Fig. 1) also differed substantially among flours. F5 and particularly F7, were notable for reaching peak viscosity later. This could be related to the larger particle size of F5, but not in F7, where greater particle compactness, despite the smaller particle size, may have contributed to this (Roman et al., 2017). Flours F1 and F7, and especially F3 and F5, showed lower peak viscosities, which may be linked to protein content (Wu et al., 2023) or to other components reducing starch content, since starch is the main substance responsible for gelatinization, retrogradation, and the resulting viscosity increase. The amount of damaged starch may also be a significant factor, as it reduces peak viscosity (Qin et al., 2021). Final viscosity also varied among flours. Traditionally, these differences have been associated with amylose content, since amylose retrogrades more readily than amylopectin. More recent research has shown that the fine structure of these compounds, particularly amylose chain length, also affects this phenomenon (Hu et al., 2020), which is closely related to the final texture of gluten-free breads.

These differences confirm that commercial flours display diverse properties, which can lead to variations in bread volume. Indeed, previous studies have demonstrated the influence of factors such as particle size and WBC on the volume of gluten-free breads (Cornejo and Rosell, 2015).



Control: black solid line; F1: Grey solid line; F2: Grey dashed line; F3: Red solid line; F4: Red dashed line; F5: Blue solid line; F6: Blue dashed line; F7: Green solid line; Temperature: Orange solid line

**Fig. 1.** Pasting properties of different flours.

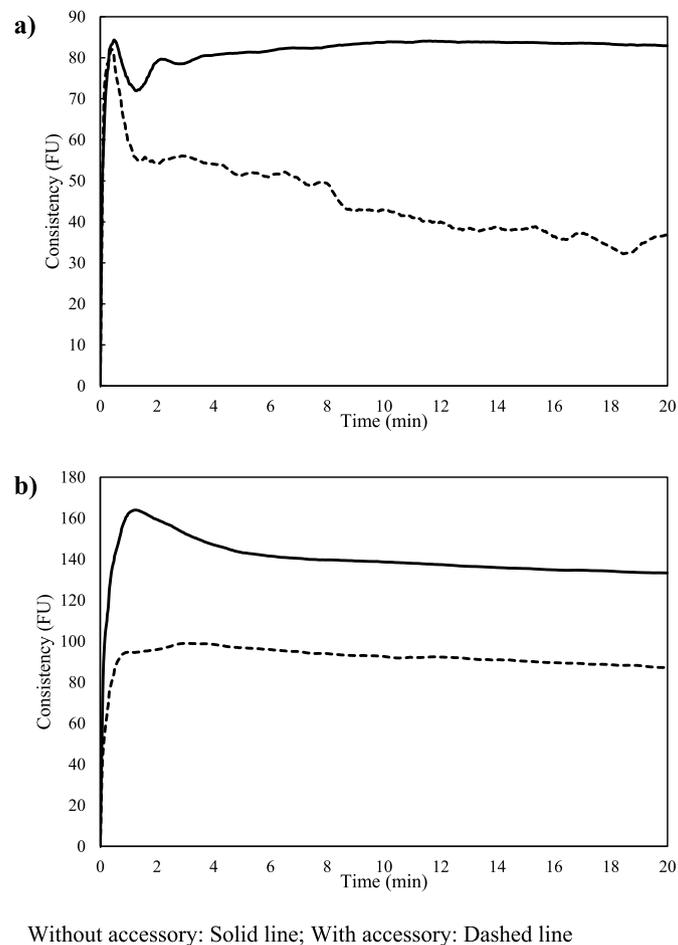


Fig. 2. Farinographic curves of the control flour (a) and of the dough made with this flour (b) with and without accessory.

### 3.2. Farinographic analysis

Farinograms for both flours and doughs, with and without the accessory, using the control flour, are shown in Fig. 2. Similar curves were obtained with and without the accessory. The main differences were a more pronounced peak and lower consistency in doughs without the accessory. These curves resemble those of wheat doughs, where an initial increase, corresponding to gluten network development, is followed by a decrease in consistency related to network weakening (Don, 2022). Although its usefulness has been questioned, the farinograph remains the reference instrument for determining the optimal dough development time (Parenti et al., 2021).

In gluten-free doughs, however, these changes cannot be attributed to gluten, as no gluten network is present. Instead, this phase reflects ingredient mixing and hydration. For starch (native or from flours), cold swelling and the glass transition of amorphous domains occur, enabling starch to act as a structural agent in the continuous phase alongside hydrocolloids used to replace the gluten network (Roman et al., 2021). The initial increase in consistency appears to be related to water absorption by flour or dough components, similar to observations in wheat doughs when high-water-absorption ingredients such as fiber are added (Verbeke et al., 2024). The subsequent weakening may be linked to mild enzymatic hydrolysis (Nakata et al., 2017) caused by endogenous rice flour enzymatic activity (Dhaliwal et al., 1991).

For the flours, the onset and peak consistency were very similar in both tests, but with the accessory, the curve showed a clear decline in consistency, which was not observed without it. This demonstrates differences between flour and dough analyses, and between analyses with or without the accessory. This study only considered peak consistency,

but future work should investigate the entire curve, how different factors affect it in gluten-free doughs and its impact on bread quality.

Trials were conducted with and without the accessory for all doughs studied (replacing the control flour with the seven commercial rice flours). Maximum consistency results with and without the accessory were significantly correlated at the 99.9 % level ( $r = 0.95$ ), indicating that similar results can be obtained with both systems. For the remainder of the study, the accessory was used, as it required less dough and avoided impacts on the external bowl lid, which risked damaging the equipment in certain tests.

Table 2 shows maximum consistency values for all doughs in both types of tests. The different flours had markedly different effects on dough consistency. F1 and F2 greatly increased consistency, F3 and F4 had a smaller effect, while F5, F6, and F7 produced consistencies more similar to the control, though with slight differences depending on the system. For example, F7 did not differ significantly from the control with the accessory but did without it, while F5 showed the opposite. These discrepancies may result from the geometry of the mixing space, which differs with and without the accessory. Therefore, it is important to choose a specific system for analysis if results are to be compared.

Correlation between maximum consistency values for rice flours and their corresponding doughs was also examined. Using the accessory, correlation was significant at the 99 % level ( $r = 0.87$ ), while without the accessory it was significant at the 99.9 % level ( $r = 0.93$ ). In both cases, analysis of the flours provided information similar to that obtained from dough analysis. For flour farinograms, significant correlations were observed between WBC and maximum consistency: at the 95 % level ( $r = 0.73$ ) without the accessory, and at the 99 % level ( $r = 0.89$ ) with the accessory. Similar correlations have been reported for wheat

**Table 2**

Maximum consistency of flours and doughs with and without the accessory, volume, and specific volume of breads with constant and adapted hydration.

	Dough consistency (FU)		Flour consistency (FU)		Bread volume (cm <sup>3</sup> )		Bread specific volume (cm <sup>3</sup> /g)	
	With Accessory	Without Accessory	With Accessory	Without Accessory	Constant hydration	Adapted hydration	Constant hydration	Adapted hydration
CONTROL	99.43 ± 1.40 <sup>a</sup>	163.98 ± 3.53 <sup>b</sup>	82.05 ± 0.75 <sup>b</sup>	85.59 ± 2.42 <sup>b</sup>	552.67 ± 15.95 <sup>f</sup>	552.67 ± 15.95 <sup>cd</sup>	5.56 ± 0.20 <sup>e</sup>	5.56 ± 0.20 <sup>cd</sup>
F1	156.40 ± 5.63 <sup>e</sup>	245.90 ± 3.51 <sup>f</sup>	304.11 ± 2.80 <sup>f</sup>	213.15 ± 2.90 <sup>f</sup>	327.33 ± 2.08 <sup>a</sup>	456.67 ± 4.93 <sup>a</sup>	3.20 ± 0.02 <sup>a</sup>	4.54 ± 0.08 <sup>b</sup>
F2	163.80 ± 11.42 <sup>e</sup>	239.37 ± 4.25 <sup>e</sup>	316.20 ± 2.84 <sup>g</sup>	236.38 ± 4.22 <sup>g</sup>	339.33 ± 1.15 <sup>a</sup>	537.33 ± 7.77 <sup>c</sup>	3.24 ± 0.03 <sup>a</sup>	5.46 ± 0.26 <sup>c</sup>
F3	138.73 ± 5.49 <sup>d</sup>	202.61 ± 2.85 <sup>d</sup>	388.28 ± 4.27 <sup>h</sup>	216.01 ± 2.85 <sup>f</sup>	416.67 ± 14.15 <sup>b</sup>	566.00 ± 6.25 <sup>d</sup>	4.04 ± 0.10 <sup>b</sup>	6.06 ± 0.11 <sup>e</sup>
F4	136.08 ± 5.66 <sup>d</sup>	200.61 ± 2.82 <sup>d</sup>	196.40 ± 1.40 <sup>e</sup>	176.81 ± 4.28 <sup>e</sup>	485.67 ± 6.35 <sup>cd</sup>	541.00 ± 6.25 <sup>c</sup>	4.77 ± 0.12 <sup>c</sup>	5.72 ± 0.10 <sup>d</sup>
F5	118.86 ± 5.65 <sup>bc</sup>	166.40 ± 0.56 <sup>b</sup>	99.02 ± 0.08 <sup>c</sup>	117.71 ± 2.80 <sup>c</sup>	513.00 ± 31.24 <sup>e</sup>	567.67 ± 5.13 <sup>de</sup>	5.20 ± 0.39 <sup>d</sup>	5.99 ± 0.06 <sup>e</sup>
F6	113.59 ± 4.26 <sup>b</sup>	188.10 ± 1.39 <sup>c</sup>	116.94 ± 1.35 <sup>d</sup>	146.50 ± 0.73 <sup>d</sup>	481.67 ± 2.08 <sup>c</sup>	585.33 ± 14.19 <sup>e</sup>	4.75 ± 0.02 <sup>c</sup>	5.98 ± 0.12 <sup>e</sup>
F7	99.90 ± 3.52 <sup>a</sup>	137.62 ± 1.38 <sup>a</sup>	39.86 ± 0.56 <sup>a</sup>	73.42 ± 4.70 <sup>a</sup>	487.67 ± 14.57 <sup>cd</sup>	487.67 ± 14.57 <sup>b</sup>	4.19 ± 0.04 <sup>b</sup>	4.19 ± 0.04 <sup>a</sup>

Values ± standard deviations followed by different letters indicate significant differences ( $p < 0.05$ ).

flours (Duyvejonck et al., 2012). As these authors noted, this correlation is logical since both methods assess flour WBC. However, they also emphasized that these are different methods with potentially distinct applications.

In contrast, no statistically significant correlation was found between WBC and dough farinograms. This suggests that when other ingredients are introduced, changes in water absorption occur due to both the reduced relative contribution of the flour and the interactions or competition between ingredients.

Regarding differences among flours, those producing doughs with higher consistency (F1, F2, and F3) also generated flour curves with higher consistencies, with or without the accessory. F4, however, showed lower consistency than F3 in flour analyses, despite being similar in doughs. F5 and F6 displayed values slightly higher than the control, both in flours and doughs. F7 showed much lower values with the accessory, in contrast to doughs, where results were similar to the control. Without the accessory, F7 produced slightly lower values than the control in both cases. As with doughs, it is evident that using or omitting the accessory affects the values obtained, and that interactions with other ingredients may in some cases modify results.

### 3.3. Baking trials

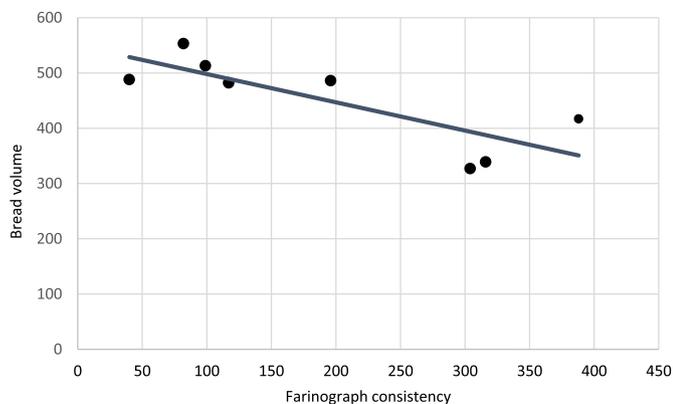
Baking trials revealed a significant correlation at the 99 % level ( $r = -0.90$ ) between bread volume and the maximum consistency of farinograph tests conducted on doughs (with the accessory). This relationship between water absorption values, linked to flour composition, had already been observed in studies with wheat breads (Duyvejonck et al., 2012). In wheat, however, the influence of other farinographic parameters, more closely associated with protein quality, proved even more important. Numerous studies have attempted to relate flour quality parameters, such as farinographic quality, with bread volume in wheat, but correlation coefficients above 0.90 are rare (Stojceska and

Butler, 2012). Thus, the correlation observed here can be considered notably strong. By contrast, no equivalent studies have been conducted for gluten-free breads, making this a first attempt to establish such a relationship.

In our study, breads produced with flours generating higher dough consistencies were those of the lowest volume, particularly F1, F2, and F3. In contrast, F4–F7 produced breads of volumes more comparable to one another, though all lower than the control. Notably, F4, which exhibited a consistency similar to F3 in both flour and dough analyses (with and without the accessory), yielded breads with somewhat greater volume. This is consistent with its flour analysis, where F4 already displayed values closer to the control than F3. Flour F7 is also noteworthy, as it yielded breads of lower volume than the control despite generating doughs or flour–water mixtures with equal or even lower consistency. Thus, although a good correlation exists, other factors beyond dough consistency may influence bread volume. Among these, differences in the enzymatic activity of flours (Dhaliwal et al., 1991) or pasting behavior, which is linked to the termination of oven spring during baking (Roman et al., 2021), may be relevant. F3 and F4, for example, displayed markedly different behaviors in the initial phase of the RVA analysis, as did F7 compared with the others.

A significant correlation was also found at the 95 % level ( $r = -0.80$ ) between the maximum consistency of flour farinograms and bread volume (Fig. 3). This demonstrates once again that, while dough analysis provides more useful results, flour analysis alone already yields valuable information. Such analysis could be highly useful in gluten-free bread-making industries for accepting or rejecting new flour samples, or for defining specifications.

Conversely, no statistically significant correlations (95 % or higher) were found between WBC or D (4,3) values and bread volume, although in general, flours with lower WBC tended to produce breads of greater volume. This suggests that farinographic analysis is a better predictor of bread volume than other flour characteristics typically used for flour characterization. These differences in predictive ability had already been demonstrated by Duyvejonck et al. (2012), who reported WBC to be more useful for predicting biscuit diameter, with both parameters



**Fig. 3.** Correlation between the maximum consistency of flour farinograms and bread volume.

**Table 3**

Differences in the volume and specific volume of the different breads with the control bread.

	Volume Constant hydration	Volume Adapted hydration	Specific volume Constant hydration	Specific volume Adapted hydration
Control	0,00 %	0,00 %	0,00 %	0,00 %
F1	40,77 %	17,37 %	42,45 %	18,35 %
F2	38,60 %	2,78 %	41,73 %	1,80 %
F3	24,61 %	-2,41 %	27,34 %	-8,99 %
F4	12,12 %	2,11 %	14,21 %	-2,88 %
F5	7,18 %	-2,71 %	6,47 %	-7,73 %
F6	12,85 %	-5,91 %	14,57 %	-7,55 %
F7	11,76 %	11,76 %	24,64 %	24,64 %
Mean	21,13 %	3,28 %	24,49 %	2,52 %

equally useful for predicting wheat bread volume, though less so than gluten quality parameters. These differences are based on time and mechanical action, and it appears evident that, in gluten-free breads—where protein quality is not of primary importance—the farinograph, which better simulates what occurs during breadmaking, is a more reliable predictor than WBC.

To adjust dough hydration and achieve consistent dough consistencies, farinograph analysis of doughs with the accessory was used. Full dough analyses were chosen because, unlike wheat doughs—essentially mixtures of flour and water (with small amounts of salt and yeast removed)—gluten-free bread formulations are much more complex, with a lower proportion of starchy ingredients relative to the total formulation. This approach thus worked with a mixture much closer to the final dough (excluding yeast to avoid fermentation effects). Adapted hydration values are shown in Table 2. As expected, a highly significant correlation was observed at the 99.9 % level ( $r = 0.92$ ) between consistency values at constant hydration and hydration values required to achieve constant consistency. In other words, the higher the initial maximum consistency, the greater the hydration needed to match the control's maximum consistency.

Baking trials were also conducted using adapted hydration values. Table 3 shows differences in volume and specific volume of breads compared with the control, under both constant and adapted hydration. While differences in bread volume under constant hydration ranged from 40.77 % to 7.18 %, with a mean of 21.13 %, in the case of adapted hydration, these differences were reduced to a maximum of 17.37 % and a minimum of 2.11 %, with a mean of 3.28 %. Similar results were observed for specific volume. Thus, hydration adjustment markedly reduced differences caused by flour type. Sahin et al. (2020), in a study involving different hydrocolloids, also reported that farinograph-based hydration correction improved gluten-free bread quality to a greater extent than WBC. However, in that case, it did not equalize bread volume but rather contributed as one of several quality-improving factors. In our study, only two flours presented bread volumes differing from the control by more than 6 %. For F1, these differences amounted to 17.37 %, though they were reduced by 57 % compared with constant hydration. For F7, which under constant hydration yielded dough consistencies very similar to the control, differences remained at 11.76 %. This flour displayed unusual behavior compared with the rest, as despite being among those with the smallest particle size, it had one of the lowest water absorption capacities, and reached its RVA peak gelatinization point later than all others. In the farinograph analysis, it also exhibited a curve that decreased less during kneading. This latter effect may be attributable to low enzymatic activity, since enzymes such as amylases and proteases can degrade grain components and reduce dough consistency. As noted earlier, this suggests that although differences in dough consistency may explain many changes in bread volume, other factors also contribute to this process. These include enzymatic activity, which is not directly captured by this measurement.

#### 4. Conclusions

Farinographic analysis, and likely other analyses examining dough consistency during mixing, provide information that helps to differentiate between flours in terms of their suitability for producing gluten-free breads of a consistent volume. It also allows dough hydration to be corrected, thereby standardizing bread volume across different flours. It is possible that such analyses may also compensate for differences between starches or other thickening agents, though further studies are required.

#### CRediT authorship contribution statement

**Silvia de Pablo:** Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation. **Diogo Salvati:** Writing – review & editing, Investigation, Formal analysis. **Manuel Gómez:** Writing –

review & editing, Writing – original draft, Validation, Supervision, Resources, Project administration, Formal analysis, Data curation, Conceptualization.

#### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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#### Data availability

Data will be made available on request.

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