International Journal of Food Science + Technology

Original article

Effects of particle size in wasted bread flour properties

Priscila Guerra-Oliveira, Juan Fernández-Peláez, Cristina Gallego & Manuel Gómez

Food Technology Area. College of Agricultural Engineering, University of Valladolid, Palencia, Spain

(Received 14 December 2021; Accepted in revised form 13 February 2022)

Abstract Bread is wasted at different stages in the food value chain, mainly in industry and retail markets. Wasted bread can be milled into flour to be used in the elaboration of other food products. Milling can generate flours with different particle sizes that influence their properties. This study analysed the effect of particle size (200, 500 and 1000 μm) on the hydration, pasting and gel properties of flours elaborated with four different stale breads. Bread flours show a higher cold water absorption capacity and a lower oil absorption capacity than wheat flour. No differences in water absorption properties after heating were observed. The viscosity curves of bread flours presented lower values than wheat flour curves, and the gels obtained were weaker. Bread flour properties were not influenced by different particle sizes. Therefore, a less aggressive milling, with a lower energy cost, can generates flours with properties similar to finer flours.

Keywords bread flour, particle size, rheology, wasted bread.

Introduction

The global food waste is estimated at 1/3 of total food production per year (FAO, 2014). In Europe, this waste represented 88 million tonnes or 173 kilograms per person per year (Stenmarck *et al*., 2016). Besides the economic issue, these values also represent a waste of natural resources and contribute to environmental impacts (Brancoli *et al*., 2019).

In the European Union, the percentage of bakery product waste is calculated to be above 7% of the total production. This percentage is estimated roughly as 1.3 million tons per year (Mena *et al*., 2011). Bakery product waste, including bread waste, occurs throughout the food supply chain, from production to transport and storage (Benabda *et al*., 2018). Bread waste includes the crust discarded for crustless loaf bread production which represents almost 40% of the final product (Verni *et al*., 2020).

Wasted bread has been used both for ethanol production (Haroon *et al*., 2016) and for animal feed (Afzalzadeh *et al*., 2007). However, according to the Waste Framework Directive, the priority of food waste reuse should be upcycling edible waste into the human consumption chain (European Union, Directive 2008/98/EC).

Wasted lean breads frequently stale before the development of microorganisms, so they are discarded with a low microbial activity and can be milled to be used in the elaboration of other products (Fernández-Peláez *et al*., 2021). The baking process promotes changes in the bread structure due to the presence of high temperatures and the moisture of the dough, which enable starch gelatinisation (Martínez *et al*., 2013). High temperatures during baking also lead to gluten denaturation, which limits gluten functionality for further uses (Pagani *et al*., 2020), and the inactivation of the enzymes present in the dough (Hug-Iten *et al*., 2003).

The use of bread flour in the production of snacks (Samray *et al*., 2019), sourdough (Gélinas *et al*., 1999), bread (Meral & Karaoğlu, 2020) and cookies (Guerra-Oliveira *et al*., 2021) has been studied. Flours obtained from bread crust or crumb of different bread types have also been characterised (Fernández-Peláez *et al*., 2021). In this study, bread flour was made using a hammer mill, using a sieve with the same mesh size in all grindings. However, different milling systems can produce flours with different particle sizes, which can influence flour properties, such as water holding capacity, solubility, colour parameters and rheology. Milling techniques can affect molecular and structural starch properties because of frictional heat and mechanical energy (Protonotariou *et al*., 2014). The differences between the properties of flours with different particle sizes have been verified in articles that study different milling systems (Bourre *et al*., 2019; Tian *et al*., 2022), or in the same milling, but separating different fractions by means of sieves (Belorio *et al*., 2019). These differences have been shown to influence the quality of products made with these flours, such as breads (de la Hera *et al*., 2013; Navarro *et al*., 2022), cakes

*Correspondent
E-mail: pallares@iaf.uva.com

doi:10.1111/ijfs.15656

(Wilderjans *et al.*, 2013) or cookies (Pareyt & Delcour, 2008). Even though particle size is known to influence flour properties, no study has evaluated its effect on bread flours.

The aim of this study was to analyse the effects of different particle sizes on bread flour properties. A milling system similar to that used in grinding many grains has been chosen, where the sample is fractioned until it passes through a sieve with a given mesh size. As for the particle sizes, one very close to that of cereal flours (<200 micrometres) and two other coarser and more usual in this type of study (<500 micrometres and <1000 micrometres) have been chosen. Therefore, four types of bread were chosen and milled with three different particle sizes (<200, <500 and <1000 micrometres) to produce twelve distinct bread flours. The hydration, rheology, pasting and gel properties of bread flours were studied and compared with the results obtained from wheat flour.

Materials and methods

Materials

Four types of wasted bread (baguette, 100% whole wheat baguette, candeal bread and loaf bread crust) were used to produce bread flours. The list of ingredients of all breads is presented in Table 1. They were chosen for their specific characteristics as follows: (1) baguette bread is the most consumed (or popular) and the most wasted type of bread in Spain; (2) whole wheat bread has a high bran and fibre content; (3) candeal bread is typical of Spain and is characterised by the low water content of its recipe and (4) loaf bread crust is a huge by-product originated from the crustless loaf bread production. All bread types were purchased from a Carrefour supermarket (Palencia, Spain). For two different batches, breads were bought on different days. For comparative purposes, wheat flour (10.8 g/100 g moisture; 8.98 g/100 g protein) supplied by Harina Castellana S.A. (Valladolid, Spain) was used as the control sample.

Table 1 List of ingredients of the breads analysed

Breads		**List of ingredients**
Baguette bread		wheat; water; salt; yeast; malt.
100% whole wheat loaf		whole wheat; water; wheat gluten; salt; yeast; vegetable extracts; esters of mono- and diacetyl tartaric acid; esters of mono- and diglycerides; lactic acid; ascorbic acid.
Loaf bread crust		Wheat; yeast; sugar; sunflower oil; salt; esters of mono- and diacetyl tartaric acid esters of mono- and diglycerides; sodium stearoyl-2-lactylate; calcium propionate; ascorbic acid; lactic acid.
Candeal bread		wheat; water; yeast; salt; calcium carbonate; soy lectin; ascorbic acid.

Methods

Milling

Breads were allowed to dry at room temperature, until reaching a humidity of less than 11%, before the milling process, which was carried out using an ultra-centrifugal mill Retsch, ZM 200 (Düsseldorf, Germany). Sieves of 1000, 500 and 200-μm mesh screen were used to obtain different particle sizes: <1000 micrometres, <500 micrometres and <200 micrometres. Samples were named according to the bread type: loaf bread crust (LF), candeal bread (CF), whole wheat bread (WF) and baguette (BF), and the particle size (1000 um, 500 um, 200 um).

Flour particle size and colour

Particle size was evaluated using a Mastersizer 3000 (Malvern Instruments, Malvern, UK) and values of D [4,3], which account for the equivalent spherical diameter of the particles, were obtained.

For colour analysis, a sample of the flour was placed in a cylindrical plastic recipient with 30 mm diameter and 15 mm height. The excess flour was removed with a plastic spatula to provide a flat and homogeneous surface. Flours were measured in the CIE $L^*a^*b^*$ colour space with a PCE-CSM 2 colorimeter (PCE Instruments, Meschede, Germany) with a D65 Illuminant with 2° Standard. The measurements were performed at the central point of the surface of the flour. Five samples of each flour were analysed and the results were calculated as their average value.

Hydration properties

Water binding capacity (WBC) measures the water retained by the sample after centrifugation; it was conducted according to method 56-30.01 (AACC, 2012a). Water holding capacity (WHC) measures the water absorption capacity with no stress influence; it was determined by slightly modifying the method proposed by (de la Hera *et al.*, 2013a). Flour sample of 5 g was dispersed in 100 mL of distilled water and kept at room temperature for 24 h. Then, the water not retained by the flour was eliminated. Both WBC and WHC analyses were made in duplicate and were expressed as gram of water retained per gram of solid.

Oil absorption capacity (OAC) was measured according to Cornejo & Rosell (2015). Samples of 100 mg were mixed with 1 mL of sunflower oil, stirred for 1 min and then vortexed for 30 min. Next, samples were centrifuged (3000 × g and 4 °C) for 10 min. After removing the supernatant, the solid residue was inverted and allowed to rest for 25 min to guarantee the complete absence of supernatant. The OAC was expressed as gram of oil bound per gram of the sample on dry basis. The analysis was made in triplicate.

The water absorption index (WAI) was calculated according to Kaur & Singh (2005); it evaluates the amount of water retained by the sample after heating. The samples with 2.5 g were dispersed in 30 mL of water and centrifuged at 600 rpm at 90 °C for 15 min. Then, samples were subjected to a second centrifugation, at room temperature with 3000 rpm for 10 min. After removing the excess water, each sample was weighed, and WAI value was obtained through the ratio of sediment weight and the initial sample weight. The analyses were made in duplicate.

Pasting behaviour

Pasting behaviour was assessed using 3.5 g (±0.1 g) of flour and 25 g (±0.1 g) of distilled water. The RVA standard cycle was used, with an initial hold for 1 min at 50 °C followed by an increase to 95 °C with a hold at that temperature for 2 min 30 s and a decrease to 50 °C with a hold at that temperature for 4 min, according to method 61-02.01 (AACC, 2012b). All measurements were performed in duplicate.

Gel texture and colour

To analyse gel texture, samples were prepared with 5 g of flour and 25 g of water and a heating standard cycle was performed in RVA (method 61-02.01, AACC, 2012). The gels obtained were stored in a round plastic container of 30 mm in diameter and 15 mm in height for 24 h at 4 °C. Before texture measurements, samples were rested at 25 °C for 30 min. The texture analyser (TA. XT2i texture analyser Stable Micro Systems Ltd., Surrey, UK) was loaded with a 5 kg cell with a P/6 probe that produced a constant velocity of 0.5 mm/sec into the sample and with a depth of 5 mm. The curve obtained provided values of the peak strength. The analyses were made in duplicate.

Gel colour was measured in the CIE $L^*a^*b^*$ colour space with a PCE-CSM 2 colorimeter (PCE Instruments, Meschede, Germany) with a D65 Illuminant with 2° Standard. The measures were performed on two different points of each sample in two batches.

Statistical analysis

Statgraphics Centurion XVI software (Statpoint Technologies, Warrenton, USA) was used. Analysis of variance (ANOVA) was applied and Tukey's HSD was used to determine significant differences among means, within 95% confidence intervals.

Results and discussion

Particle size and colour

According to the results presented in Table 2, although the particle size of the flours, D[4,3] decreases when the mesh size of the sieve placed in the

Table 2 Bread flour particle size and colour

	D [4;3]	L^*	a^*	b^*
Wheat flour	111 ± 1.41a	89.94 ± 2.75f	1.13 ± 0.16 a	10.70 ± 0.02a
LF200	112.0 ± 2.8a	84.21 ± 0.31def	6.30 ± 0.14b	17.98 ± 0.02b
LF500	180.5 ± 4.9c	80.67 ± 0.24de	7.60 ± 0.05bcd	19.74 ± 0.02bc
LF1000	276.0 ± 2.8fg	77.92 ± 0.31 cd	7.83 ± 0.40bcde	20.37 ± 0.55bcd
CF200	145.5 ± 0.7b	85.73 ± 1.31ef	5.11 ± 0.30b	18.48 ± 0.30bc
CF500	231.0 ± 2.8d	83.78 ± 0.24def	6.05 ± 0.22b	19.95 ± 0.61bcd
CF1000	240.0 ± 2.8de	82.37 ± 0.56de	6.39 ± 0.25b	20.26 ± 0.25bcd
WF200	153.0 ± 1.4bc	73.64 ± 2.45bc	9.56 ± 0.83cde	22.42 ± 0.3def
WF500	265.5 ± 6.4ef	67.97 ± 1.39ab	10.58 ± 0.74de	23.33 ± 0.59f
WF1000	285.5 ± 0.7fg	65.29 ± 2.79a	10.65 ± 0.73e	23.00 ± 0.37ef
BF200	165.0 ± 9.9bc	84.61 ± 2.31def	5.91 ± 1.41b	18.65 ± 1.04bc
BF500	266.0 ± 18.4ef	81.87 ± 1.54de	6.90 ± 1.30bc	20.07 ± 1.14bcd
BF1000	298.5 ± 10.6g	81.01 ± 2.22de	7.17 ± 1.17bc	20.58 ± 1.11cde

LF: loaf flour; CF: candeal flour; WF: whole-wheat flour; BF: baguette flour; D[4,3]: average particle size which constitutes the bulk of the sample volume; L*: lightness; a*: green-red axis; b*: blue-yellow axis. The values with the same letter in the same column do not present significant differences ($p < 0.05$).

mill decreases, there are no significant differences between those below 500 and 1000 microns, in the case of CF and WF breads, and are smaller in the BF than in the LF. This effect is better appreciated in the distribution curves of the particle size of the flours (Figure S1). All the flours obtained were coarser when compared to wheat flour, with the exception of LF200, which did not differ significantly from wheat flour. Flours obtained with BF and WF had a larger particle size, while the LF flours were the finest, although significant differences were only observed in samples obtained with sieves below 1000-μm. It should be noted that the bread that generates the finest flours with the smallest sieves is also the one that shows the clearest differences between the particle sizes obtained with different sieves. The particle size of the flours is related to the hardness of the materials to be milled. For milled breads, during staling starch retrogradation occurs (Gray & Bemiller, 2003), which increases hardness and therefore to particle size, since softer samples break more easily and into smaller particle sizes. Thus, ingredients such as oil present in loaf bread reduce hardness by minimising retrogradation (Chen *et al*., 2017), and could explain the lower particle size values observed in these flours.

Regarding flour colour, there is a small difference in colour between LF and flours obtained in CF and BF, as loaf bread crust presents a light colour. This variation among bread types can be explained by differences in baking conditions (Purlis & Salvadori, 2009). The WF flours presented higher values of *L**, *a** and *b**. This is related to a large amount of wheat bran, with a darker colour and brownish tones than the endosperm. Therefore, the lower the degree of extraction with less amount of bran, the higher the L values of the flour (Bhatty, 1997). The bran colour can also differ due to genetic characteristics (Grafenauer *et al*., 2020). Among the other flours, no significant differences were found for the same particle size in any of the parameters analysed. It is noteworthy that bread flours have lower *L** and higher *a** and *b** values than wheat flour. This is mainly due to the high temperatures reached on the outside of the pieces during baking, which facilitate Maillard reactions and caramelisation of sugars and generate brown colours (Purlis, 2010). In fact, Fernández-Peláez *et al*. (2021) have already observed that bread crust flours had higher *a** and *b** values and lower *L** values than those obtained from crumbs. In terms of particle size, there is a tendency for *L** values to increase and for a decrease in *a** and *b** as the particle size decreases. Other studies have already detected this tendency from the endosperm of different cereals with distinct particle size (Hidalgo *et al*., 2014; Rumler *et al*., 2021). Numerous substances that provide colour in cereal endosperm and belong to the carotenoid group can be oxidised and lose part of this colour (Mellado-Ortega & Hornero-Mendez, 2015). Finer particles have a larger surface area exposed to environmental oxygen, favouring this type of phenomena.

Hydration properties

All bread flour samples have higher WHC and WBC than wheat flour, as shown in Table 3. This is due to the higher cold hydration capacity of gelatinised starches compared to native starches (Hagenimana *et al*., 2006; Martínez *et al*., 2014), and to the fact that the gelatinisation of these starches occurs during baking processes (Martínez *et al*., 2018).

The degree of gelatinisation for all the samples was 100% or close, except for the crust which was lower. Nevertheless, all the samples presented higher values than the flours (Varriano-Marston *et al*., 1980; Martínez *et al*., 2018). Therefore, bread flours have high levels of gelatinised starch and a higher capacity for cold hydration than wheat flour. Among the different types of breads, LF presented the lowest values, but for WBC there were no significant differences, while for WHC there were differences only with CF and BF. Fernández-Peláez *et al*. (2021) have attributed these differences to the presence of such ingredients as oil and to the lower content of starch and protein responsible for water hydration. It is possible to think that in bread crusts, the gelatinised starch content is lower resulting in a lower water absorption capacity. But unlike the breads analysed by Martínez *et al*. (2018), the breads from which these crusts come are baked inside a mould. This baking process reduces

Table 3 Hydration properties of the bread flours

	WHC (g/g)	WBC (g/g)	OAC (g/g)	WAI (g/g)
Wheat flour	1.46 ± 0.01a	0.88 ± 0.04a	1.73 ± 0.03b	4.45 ± 0.24a
LF200	2.75 ± 0.05b	1.86 ± 0.02b	0.74 ± 0.11a	4.69 ± 0.80a
LF500	2.73 ± 0.16b	1.86 ± 0.01b	0.73 ± 0.10a	5.32 ± 0.55a
LF1000	2.95 ± 0.04bc	1.76 ± 0.04b	0.96 ± 0.06a	5.30 ± 0.10a
CF200	3.53 ± 0.11 cd	2.02 ± 0.12b	0.78 ± 0.16a	4.24 ± 0.31a
CF500	3.73 ± 0.06d	2.01 ± 0.13b	0.87 ± 0.16a	4.44 ± 0.42a
CF1000	3.82 ± 0.18d	2.11 ± 0.40b	0.88 ± 0.19a	4.53 ± 0.41a
WF200	3.43 ± 0.01 cd	2.06 ± 0.09b	0.84 ± 0.16a	4.11 ± 0.61a
WF500	3.33 ± 0.40bcd	1.98 ± 0.03b	0.85 ± 0.14a	4.37 ± 0.22a
WF1000	3.20 ± 0.14bcd	2.02 ± 0.07b	0.93 ± 0.10a	4.63 ± 0.15a
BF200	3.79 ± 0.01d	2.25 ± 0.11b	0.70 ± 0.02a	4.81 ± 0.84a
BF500	3.80 ± 0.24d	2.11 ± 0.11b	0.81 ± 0.10a	4.88 ± 0.35a
BF1000	3.70 ± 0.19d	2.07 ± 0.08b	0.81 ± 0.03a	4.93 ± 0.52a

LF: loaf flour; CF: candeal flour; WF: whole-wheat flour; BF: baguette flour; OAC: oil absorbance capacity; WAI: water absorbance index; WHC: water holding capacity; WBC: water binding capacity. The values with the same letter in the same column do not present significant differences ($p < 0.05$).

water evaporation and keeps the external part moist for longer, facilitating the gelatinisation of the starch.

It is striking that no trend was observed as a function of flour particle size. In other studies, significant differences have often been found on these properties. A greater effort in milling to reduce particle size increases damaged starch and therefore, the water absorption of finer flours (Protonotariou *et al*., 2021). This is more pronounced in harder grains or in the grain hardest parts and, therefore, a higher level of damaged starch is generated in these grains (de la Hera *et al*., 2013b). However, when flours of different particle sizes are obtained by sieving, the finer fractions usually contain less damaged starch (de la Hera *et al*., 2013a), although the way the remaining particles are broken can also change the composition (Rumler *et al*., 2021) and this affects hydration. Furthermore, it should be taken into account that smaller particle sizes have a larger exchange surface area and can absorb water more easily. Thus, water absorption can increase with finer particles (Rao *et al*., 2016) or reduce (Rumler *et al*., 2021). For bread flour, on the one hand, a homogeneous dough was formed with all the ingredients and, on the other, all the starch was damaged. These modifications increased significantly the water absorption capacity of the flours and, thus, no significant variation was observed in the values obtained for different particle sizes.

No significant differences were observed between any of the samples, not even between bread flour and wheat flour, in the WAI. This is because during heating starch gelatinisation occurs, just like during baking. Therefore, in both cases, the starch that absorbs water is mainly gelatinised starch. Rao *et al*. (2016) did observe differences between the WAI of sorghum flours with different particle sizes. However, in the heat treatment time of their analysis, although it does gelatinise, starch may not degrade completely (especially in the coarse particles obtained from a hard cereal such as sorghum), as it seems to occur in the baking process, where hydrated flours were subjected to high temperatures for a longer time.

As for OAC, all bread flours showed lower values than wheat flour, but no significant differences were observed for bread type or particle size. This seems to indicate that gelatinised or damaged starches have a lower oil absorption capacity, but that small variation in composition are not sufficient to cause significant differences in this parameter. Rao *et al*. (2016) also observed lower OAC values for finer flours with a higher percentage of damaged starch.

Pasting behaviour

Figure 1 shows the RVA curves of the different flour types in which all samples have substantially lower viscosity than wheat flour from the point of gelatinisation onwards. This effect is due to starch that is already gelatinised in bread flours, while pre-gelatinised flours or starches hardly increase viscosity on heating and subsequent cooling (Martínez *et al*., 2014). However, a slight increase in the viscosity of bread flours was observed at the starch gelatinisation temperature, slightly higher for BF, and lower for WF and LF, an effect that has already been observed by Varriano-Marston *et al*. (1980). Their study also found that in the internal part of the crumb, the starch had been subjected to less heat and had less unstructured granules, showing a reduced increase in viscosity. The heat treatment applied in bread making will influence the viscosity of the starches present in the bread flour. Therefore, the higher the hydrothermal treatment, the lower the ability of flours to increase their viscosity due to the amount of unstructured starch granules.

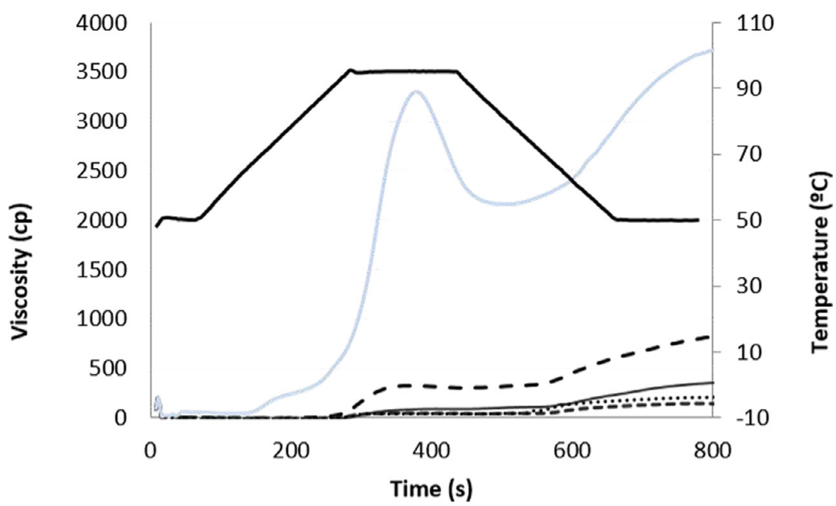

Figure 1 Paste viscosity of milled bread flours with a sieve of 200 μm and control wheat flour. Viscosity profile for baguette flour (separate dash line), whole-wheat flour (dashed line), candeal flour (fine black line), loaf-crust flour (dotted line) and wheat flour (gray line) are represented in vertical axis. Temperature profile is represented by thick black line.

The differences between BF and CF flours may result from the different baking conditions and, therefore, different degradation of the starch granules. In contrast, in the case of WF and LF flours, the presence of other ingredients, such as oil and bran, with no capacity to increase their viscosity when the temperature is increased, could explain their lower viscosity along the curve, as already observed by Fernández-Peláez *et al.* (2021) in the rheology of the doughs obtained.

Figures 2a-d show the differences in the RVA curves of the different bread flours as a function of particle size. In this case, no differences were found except for LF, where a slightly higher viscosity is observed in the case of finer flours. In the literature, several studies explain changes in pasting temperature and viscosity along the curve when the particle size is modified (Román *et al.*, 2017; Ahmed *et al.*, 2019; Guan *et al.*, 2020). However, it differs according to the type of grain and the method of flour production. Edwards *et al*, (2015) have stated that the effect of particle size on gelatinisation behaviour depends not only on surface area, but also on the integrity of the starch inside the particles. The increase in the pasting temperature of coarser particles results from their structural compactness, which can be a limiting factor for the penetration of water inside the particle, necessary for starch gelatinisation (Román *et al.*, 2017; Ahmed *et al.*, 2019). Thus, coarser, more compact and harder particles with less water absorption surface can delay or minimise the gelatinisation phenomena, as the analysis is carried out in a limited and tight time frame. However, for finer particles of softer grains, such as wheat, these differences are not noticeable (Guan *et al.*, 2020). Differences in viscosity along the curve are due to starch damage in the milling process, which reduces starch ability to increase viscosity upon gelatinisation and subsequent retrogradation (Guan *et al.*, 2020). However, it may also be due to differences in the composition of each fraction if they have been obtained by sieving (Ahmed *et al.*, 2019), or to the difficulty of starch gelatinisation process inside the endosperm in coarse particles (Li *et al.*, 2014; Román *et al.*, 2017).

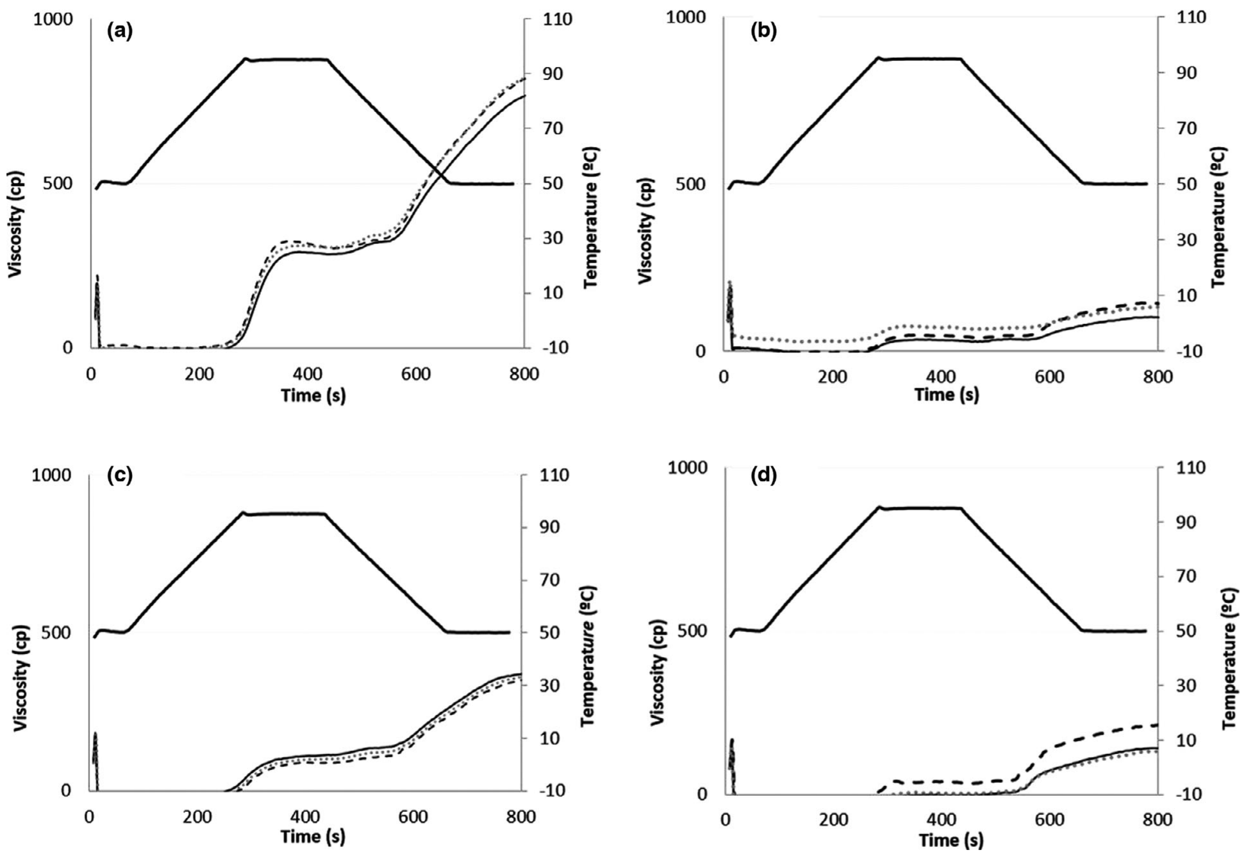

Figure 2 Paste viscosity of baguette bread flour (a), whole-wheat flour (b), candeal flour (c) and loaf crust flour (d) with different particle sizes. Viscosity profiles for 200 μm (dashed line), 500 μm (fine black line) and 1000 μm (dotted line) are represented in vertical axis. Temperature profile is represented by thick black line.

In the case of bread flours, as most of the starch is gelatinised (Martínez *et al.*, 2018) and degraded (Varriano-Marston *et al.*, 1980), water is easily absorbed, with no difference in particle size, which is in agreement with the results of the hydration properties observed. In addition, there were no distinctions in the different compositions, as the flours were not separated by sieving. Particles formed compact masses where the components were more integrated than in untreated flour particles (Fernández-Peláez *et al.*, 2021).

No correlation has been found between the pasting properties of the flours and the WAI, although it is common to find this relationship between the cold water absorption capacity and the rheology of the dough. This agrees with Siguenza-Andres *et al.* (2021) who detected a correlation between WBC and the rheology of gluten-free doughs, but also did not observe a correlation between WAI and pasting properties. This may be due to the differences in the analysis conditions, as in the RVA the hydration of the samples is much higher and heating process is faster and shorter.

Gel properties

In Table 4, the gel colours obtained from bread flour show higher *a** and *b** values because Maillard reactions generate brownish tones on bread crust, which agree with the flour colour results. Fernández-Peláez *et al.* (2021) observed greater differences in colour from bread crusts flours when compared with breadcrumbs flour. However, there are no major differences in *L** values, and in general bread flour gels are somewhat lighter than wheat flour gels, although only LF200, CF200, CF500 presented significant differences. Fernández-Peláez *et al.* (2021) have also observed this effect in flours from breadcrumbs, but both observations disagree with what we saw in flour colour. Therefore, this effect could be related to the colour changes that occur in starch gelatinisation and in retrogradation process. Among the bread flour types, only WF flours differ from the rest, with higher values of *a** and *b**, and lower values of *L**, possibly related to the presence of bran, with brownish darker tones (more *a** and *b**). In the case of particle size, no significant differences were observed either.

These results—in line with the flour colours observed—can directly influence gel colours. Nevertheless, they also indicate that the heating process, in matrices with high water availability, does not affect the colour based on particle size. This could be related to the ease of water uptake by these flours, which may also explain the absence of differences between gel hardness (Table 4) as a function of particle size, although differences can be seen depending on the flour type. Thus, the stronger gels generated by wheat flour, as observed by Fernández-Peláez *et al.* (2021), correspond with the higher values obtained at the end of the RVA curve and are related to starch ability to gelatinise and retrograde in this process. The gels formed are harder because starch changes after gelatinisation, going from a more amorphous structure to a more crystalline and ordered one (Ribotta *et al.*, 2007). However, after heat treatment and the ensuing starch damage, the tendency of starch to form intramolecular interactions is reduced (Román *et al.*, 2018). In the case of wheat starch in particular, it is more difficult to create amylose-amylose physical junction zones. For this reason, samples with lean formulas based mainly on wheat flour as BF and CF, presented weaker gels when compared to wheat flour. These values also agree with the lower values of their RVA

Table 4 Gel colour and texture

	*L**	*a**	*b**	Peak strength (N)
Wheat flour	57.48 ± 0.01abc	-1.73 ± 0.01a	5.12 ± 0.01a	0.47 ± 0.00c
LF200	66.18 ± 1.23d	3.96 ± 0.21b	13.50 ± 0.67bcd	0.13 ± 0.00ab
LF500	64.28 ± 0.51 cd	4.03 ± 0.42b	13.17 ± 1.06bcd	0.14 ± 0.00ab
LF1000	64.58 ± 0.64 cd	3.76 ± 0.15b	12.82 ± 0.55bc	0.13 ± 0.00ab
CF200	64.10 ± 0.51def	2.65 ± 0.24b	11.27 ± 0.67b	0.30 ± 0.07bc
CF500	67.56 ± 3.52d	2.13 ± 0.12b	10.50 ± 0.06b	0.31 ± 0.13bc
CF1000	63.96 ± 1.67 cd	2.54 ± 0.37b	11.27 ± 0.56b	0.34 ± 0.12bc
WF200	49.56 ± 3.90a	8.11 ± 0.24c	16.95 ± 0.10e	0.01 ± 0.00a
WF500	50.31 ± 2.98a	7.66 ± 0.67c	16.10 ± 0.39de	0.01 ± 0.02a
WF1000	53.02 ± 3.26ab	7.46 ± 0.97c	16.01 ± 0.67de	0.01 ± 0.01a
BF200	62.18 ± 1.87 cd	2.84 ± 0.97b	11.16 ± 2.01b	0.24 ± 0.03b
BF500	60.55 ± 0.60bcd	2.87 ± 0.84b	11.13 ± 1.73b	0.28 ± 0.01bc
BF1000	61.02 ± 2.43bcd	2.84 ± 0.62b	10.98 ± 1.35b	0.27 ± 0.02bc

LF: loaf flour; CF: candeal flour; WF: whole-wheat flour; BF: baguette flour; L*: lightness; a*: green-red axis; b*: blue-yellow axis. The values with the same letter in the same column do not present significant differences ($p < 0.05$).

curves at the end of the retrogradation process. The LF and WF are the weakest among all. These highlight the effect of such ingredients as oil or bran. The presence of other ingredients also decreases the total amount of starch, responsible for gel formation. For WF, bran particles can also interfere with the creation of a more ordered structure, reducing gel hardness, as observed by Sozer *et al.* (2014).

Particle size did not present significant differences in gel strength, in the same was as in the other properties studied. In studies with native flours, differences were found either due to the various flour compositions if obtained by sieving (Solaesa *et al.*, 2020), or to the greater starch damage during processing if obtained by forced milling (Drakos *et al.*, 2017). However, in bread flours, since all particle sizes have the same composition and all starch is degraded in the same way, those differences are not observed. In the case of WF, bran particles can also interfere with the creation of a more ordered structure, reducing the hardness of the gels, effect that Sozer *et al.* (2014) have described as well.

Conclusions

In contrast to most cereal flours and flour from other grains, particle size in bread flours hardly influences hydration, pasting or gel properties. These differences seem to be related to the fact that starch granules have gelatinised and disintegrated in the baking process, facilitating water absorption. Therefore, when used in systems with a high amount of water, we can use coarser flours, with a lower energy expenditure in the milling process, with similar results to those obtained with finer flours. This facilitates the use of discarded bread in households where there are usually no systems for obtaining very fine flours, and reduces energy costs in industrial processing.

Acknowledgements

This work was financed by Junta de Castilla y León (VA177P20), Spain, and the TRANSCOLAB FEDER-Interreg España-Portugal project (0612_TRANS_CO_LAB_2_P).

Author contribution

Priscila Guerra-Oliveira: Conceptualization (equal); Data curation (lead); Formal analysis (lead); Investigation (equal); Methodology (equal); Validation (equal); Visualization (equal); Writing – original draft (equal); Writing – review & editing (supporting). **Juan Fernández-Peláez:** Conceptualization (equal); Formal analysis (supporting); Investigation (equal); Methodology (equal); Writing – original draft (supporting). **Cristina Gallego:** Data curation (supporting); Formal analysis (supporting); Methodology (supporting); Writing – original draft (supporting). **Manuel Gomez:** Conceptualization (equal); Funding acquisition (lead); Investigation (equal); Methodology (supporting); Project administration (lead); Supervision (lead); Validation (equal); Visualization (equal); Writing – review & editing (lead).

Ethical statement

Ethics approval was not required for this research.

Peer review

The peer review history for this article is available at https://publons.com/publon/10.1111/ijfs.15656.

Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

References

AACC. (2012a). *Method 56–40.01. Water hydration capacity of protein materials*, 11th. ed. AACC International Approved Methods.

AACC. (2012b). *Method 76–21.02. General pasting method for wheat or rye flour of starch using the Rapid Visco analyser*, 11th. ed. AACC International Approved Methods.

Afzalzadeh, A., Boorboor, A., Fazaeli, H., Kashan, N. & Ghandi, D. (2007). Effect of feeding bakery waste on sheep performance and the carcass fat quality. *Journal of Animal and Veterinary*, **6**, 559–562.

Ahmed, J., Thomas, L. & Arfat, Y.A. (2019). Functional, rheological, microstructural and antioxidant properties of quinoa flour in dispersions as influenced by particle size. *Food Research International*, **116**, 302–311.

Belorio, M., Sahagún, M. & Gómez, M. (2019). Influence of flour particle size distribution on the quality of maize gluten-free cookies. *Foods*, **8**, 83.

Benabda, O., Kasmi, M., Kachouri, F. & Hamdi, M. (2018). Valorization of the powdered bread waste hydrolysate as growth medium for baker yeast. *Food and Bioproducts Processing*, **109**, 1–8.

Bhatty, R.S. (1997). Milling of regular and waxy starch hull-less barleys for the production of bran and flour. *Cereal Chemistry*, **74**, 693–699.

Bourre, L., Frohlich, P., Young, G. *et al.* (2019). Influence of particle size on flour and baking properties of yellow pea, navy bean, and red lentil flours. *Cereal Chemistry*, **96**, 655–667.

Brancoli, P., Lundin, M., Bolton, K. & Eriksson, M. (2019). Bread loss rates at the supplier-retailer interface – Analysis of risk factors to support waste prevention measures. *Resources, Conservation and Recycling*, **147**, 128–136.

Chen, X., He, X.W., Zhang, B., Fu, X., Jane, J.L. & Huang, Q. (2017). Effects of adding corn oil and soy protein to corn starch on the physicochemical and digestive properties of the starch. *International Journal of Biological Macromolecules*, **104**, 481–486.

Cornejo, F. & Rosell, C.M. (2015). Influence of germination time of brown rice in relation to flour and gluten free bread quality. *Journal of Food Science and Technology*, **52**, 6591–6598.

Drakos, A., Kyriakakis, G., Evageliou, V., Protonotariou, S., Mandala, I. & Ritzoulis, C. (2017). Influence of jet milling and particle size on the composition, physicochemical and mechanical properties of barley and rye flours. *Food Chemistry*, **215**, 326–332.

European Union. (2008). Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives". *Official Journal of the European Union*, **51**, 3–30.

Edwards, C.H., Warren, F.J., Campbell, G.M. *et al.* (2015). A study of starch gelatinisation behaviour in hydrothermally-processed plant food tissues and implications for in vitro digestibility. *Food & Function*, **6**, 3634–3641.

FAO. IFAD. WFP., . (2014). *The State of Food Insecurity in the World 2014*. FAO, Rome: Strengthening the Enabling Environment for Food Security and Nutrition.

Fernández-Peláez, J., Guerra, P., Gallego, C. & Gómez, M. (2021). Physical properties of flours obtained from wasted bread crusts and crumbs. *Foods*, **10**, 282.

Gélinas, P., McKinnon, C.M. & Pelletier, M. (1999). Sourdough-type bread from waste bread crumb. *Food Microbiology*, **16**, 37–43.

Grafenauer, S., Miglioretto, C., Solah, V. & Curtain, F. (2020). Review of the sensory and physico-chemical properties of red and white wheat: which makes the best whole grain? *Foods*, **9**, 136.

Gray, J.A. & Bemiller, J.N. (2003). Bread staling: Molecular basis and control. *Comprehensive Reviews in Food Science and Food Safety*, **2**, 1–21.

Guan, E.Q., Yang, Y.L., Pang, J.Y., Zhang, T.J., Li, M.M. & Bian, K. (2020). Ultrafine grinding of wheat flour: Effect of flour/starch granule profiles and particle size distribution on falling number and pasting properties. *Food Science & Nutrition*, **8**, 2581–2587.

Guerra-Oliveira, P., Belorio, M. & Gómez, M. (2021). Wasted bread as main ingredient for cookie elaboration. *Foods*, **10**, 1759.

Hagenimana, A., Ding, X. & Fang, T. (2006). Evaluation of rice flour modified by extrusion cooking. *Journal of Cereal Science*, **43**, 38–46.

Haroon, S., Vinthan, A., Negron, L., Das, S. & Berenjian, A. (2016). Biotechnological approaches for production of high value compounds from bread waste. *American Journal of Biochemistry and Biotechnology*, **12**, 102–109.

de la Hera, E., Gómez, M. & Rosell, C.M. (2013). Particle size distribution of rice flour affecting the starch enzymatic hydrolysis and hydration properties. *Carbohydrate Polymers*, **98**, 421–427.

de la Hera, E., Talegon, M., Caballero, P. & Gómez, M. (2013). Influence of maize flour particle size on gluten-free breadmaking. *Journal of the Science of Food and Agriculture*, **93**, 924–932.

Hidalgo, A., Fongaro, L. & Brandolini, A. (2014). Wheat flour granulometry determines colour perception. *Food Research International*, **64**, 363–370.

Hug-Iten, S., Escher, F. & Conde-Petit, B. (2003). Staling of bread: Role of amylose and amylopectin and influence of starch-degrading enzymes. *Cereal Chemistry*, **80**, 654–661.

Kaur, M. & Singh, N. (2005). Studies on functional, thermal and pasting properties of flours from different chickpea (*Cicer arietinum* L.) cultivars. *Food Chemistry*, **91**, 403–411.

Li, E., Dhital, S. & Hasjim, J. (2014). Effects of grain milling on starch structures and flour/starch properties. *Starch*, **66**, 15–27.

Martínez, M., Oliete, B. & Gómez, M. (2013). Effect of the addition of extruded wheat flours on dough rheology and bread quality. *Journal of Cereal Science*, **57**, 424–429.

Martínez, M.M., Román, L. & Gómez, M. (2018). Implications of hydration depletion in the in vitro starch digestibility of white bread crumb and crust. *Food Chemistry*, **239**, 295–303.

Martínez, M.M., Rosell, C.M. & Gómez, M. (2014). Modification of wheat flour functionality and digestibility through different extrusion conditions. *Journal of Food Engineering*, **143**, 74–79.

Mellado-Ortega, E. & Hornero-Mendez, D. (2015). Carotenoids in cereals: an ancient resource with present and future applications. *Phytochemistry Reviews*, **14**, 873–890.

Mena, C., Adenso-Diaz, B. & Yurt, O. (2011). The causes of food waste in the supplier–retailer interface: Evidences from the UK and Spain. *Resources. Conservation and Recycling*, **55**, 648–658.

Meral, H. & Karaoğlu, M.M. (2020). The effect of the stale bread flour addition on flour and bread quality. *International Journal of Food Engineering*, **16**, 20190100.

Navarro, J.L., Biglione, C., Paesani, C., Moiraghi, M., León, A.E. & Steffolani, M.E. (2022). Effect of wheat pearling process on composition and nutritional profile of flour and its bread-making performance. *International Journal of Food Science and Technology*, **57**, 249–257.

Pagani, M.A., Giordano, D., Cardone, G. *et al.* (2020). Nutritional features and bread-making performance of wholewheat: does the milling system matter? *Foods*, **9**, 1035.

Pareyt, B. & Delcour, J.A. (2008). The role of wheat flour constituents, sugar, and fat in low moisture cereal based products: A review on sugar-snap cookies. *Critical Reviews in Food Science and Nutrition*, **48**, 824–839.

Protonotariou, S., Drakos, A., Evageliou, V., Ritzoulis, C. & Mandala, I. (2014). Sieving fractionation and jet mill micronization affect the functional properties of wheat flour. *Journal of Food Engineering*, **134**, 24–29.

Protonotariou, S., Ritzoulis, C. & Mandala, I. (2021). Jet milling conditions impact on wheat flour particle size. *Journal of Food Engineering*, **294**, 110418.

Purlis, E. (2010). Browning development in bakery products—A review. *Journal of Food Engineering*, **99**, 239–249.

Purlis, E. & Salvadori, V.O. (2009). Bread browning kinetics during baking. *Journal of Food Engineering*, **80**, 1107–1115.

Rao, B.D., Anis, M., Kalpana, K., Sunooj, K.V., Patil, J.V. & Ganesh, T. (2016). Influence of milling methods and particle size on hydration properties of sorghum flour and quality of sorghum biscuits. *LWT-Food Science and Technology*, **67**, 8–13.

Ribotta, P.D., Colombo, A., León, A.E. & Añón, M.C. (2007). Effects of soy protein on physical and rheological properties of wheat starch. *Starch*, **59**, 614–623.

Román, L., Gómez, M., Li, C., Hamaker, B.R. & Martínez, M.M. (2017). Biophysical features of cereal endosperm that decrease starch digestibility. *Carbohydrate Polymers*, **165**, 180–188.

Román, L., Gómez, M., Hamaker, B.R. & Martínez, M.M. (2018). Shear scission through extrusion diminishes inter-molecular interactions of starch molecules during storage. *Journal of Food Engineering*, **238**, 134–140.

Rumler, R., Bender, D., Speranza, S. *et al.* (2021). Chemical and physical characterization of sorghum milling fractions and sorghum whole meal flours obtained via stone or roller milling. *Foods*, **10**, 870.

Samray, M.N., Masatcioglu, T.M. & Koksel, H. (2019). Bread crumbs extrudates: A new approach for reducing bread waste. *Journal of Cereal Science*, **85**, 130–136.

Siguenza-Andres, T., Gallego, C. & Gómez, M. (2021). Can cassava improve the quality of gluten free breads? *LWT-Food Science and Technology*, **149**, 111923.

Solaesa, A.G., Villanueva, M., Vela, A.J. & Ronda, F. (2020). Protein and lipid enrichment of quinoa (cv.Titicaca) by dry fractionation. Techno-functional, thermal and rheological properties of milling fractions. *Food Hydrocolloids*, **105**, 105770.

Sozer, N., Cicerelli, L., Heiniö, R.-L. & Poutanen, K. (2014). Effect of wheat bran addition on in vitro starch digestibility, physico-mechanical and sensory properties of biscuits. *Journal of Cereal Science*, **60**, 105–113.

Stenmarck, Å., Jensen, C., Quested, T. & Moates, G.(2016). Estimates of European food waste levels. In Fusions; EU-Fusions: Stockholm Sweden. Estimates of European Food Waste Levels. *Fusions; EU-Fusions*. Stockholm Sweden.

Tian, X., Wang, X., Ma, S., Sun, B., Qian, X. & Gu, Y. (2022). Effect of different milling mechanical forces on the structures and properties of wheat flour. *International Journal of Food Science and Technology*, https://doi.org/10.1111/ijfs.15202

Varriano-Marston, E., Ke, V., Huang, G. & Ponte, J. (1980). Comparison of methods to determine starch gelatinization of bakery foods. *Cereal Chemistry*, **57**, 242–248.

Verni, M., Minisci, A., Convertino, S., Nionelli, L. & Rizzello, C.G. (2020). Wasted bread as substrate for the cultivation of starters for the food industry. *Frontiers in Microbiology*, **11**, 293.

Wilderjans, E., Luyts, A., Brijs, K. & Delcour, J.A. (2013). Ingredient functionality in batter type cake making. *Trends in Food Science & Technology*, **30**, 6–15.

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Fig S1a
Fig S1b
Fig S1c
Fig S1d