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Original article

Effect of wheat pearling process on composition and nutritional profile of flour and its bread-making performance

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Summary Pearling process on wheat grains was evaluated as a strategy to reduce their adverse effect on whole-wheat bread (WWB) quality and simultaneously preserve part of the nutrients of the whole grain. The grains were pearled applying different times (25, 125, 225 and 250 s) before milling. Characteristic, nutritional composition and rheology of the pearled wheat flour (P), and their bread-making performance, were analysed. Whole-wheat flour and refined flour (RF) were used as control. P125s, P225s and P250s exhibited a superior nutritional profile concerning RF. P had lower water absorption and led to higher volume bread with lighter crust and crumb compared to WWB. P125s, P225s and P250s bread showed characteristics similar to those of white bread, but their hardness was lower. The improvement resulted from the extraction of the outermost bran layers, a decrease in insoluble dietary fibre, an increase in the proportion of water-soluble pentosans and a lower protein weakening.

Keywords Aleurone layer, bread-making quality, ferulic acid, pearled wheat flour.

Introduction

Regular consumption of food containing whole wheat has been reported to offer many health benefits. Whole wheat refers to the wheat grain that has been left entirely intact and still contains the nutrient-packed bran along with the germ and the endosperm. The wheat pericarp, the outermost layer of bran, is composed of dead cells with walls containing cross-linked arabinoxylan and cellulose, which is part of dietary fibre (Hemdane *et al.*, 2016). On the other hand, the aleurone layer, the innermost layer of the bran, represents ~50% of the wheat bran and contains soluble dietary fibre, as well as some essential amino acids, phenolic compounds, minerals and B vitamins (Brouns *et al.*, 2012). Both types of fibre have been associated with a lower risk of chronic diseases and several forms of cancer (Slavin *et al.*, 2001).

Despite its benefits, bran affects negatively whole-wheat bread loaf volume, crumb texture and sensory acceptance (De Brier *et al.*, 2015; Hemdane *et al.*, 2016). Detrimental effects are mainly attributed to the gluten dilution effect and disruptions in the gluten–starch network (Gan *et al.*, 1992), which refrain gas cells within the matrix from expanding. Epicarp hairs (mostly found in the outer bran layers) are also responsible for this adverse mechanical effect (Gan *et al.*, 1992). Other aspects like milling type and bran particle shape (Navarro *et al.*, 2020), strong water binding (Hemdane *et al.*, 2016), presence of reducing compounds, such as glutathione and bound ferulic acid (Noort *et al.*, 2010), and bran-associated enzyme activities (De Brier *et al.*, 2015) have also been proposed as main factors producing detriment effects on whole-wheat bread. The result is non-homogeneous and coarse crumb structure with lower loaf volume, harder texture, darker crust and bitter taste as compared to that of white bread.

Nevertheless, a promising strategy to modify the composition of wheat and its effect on bread-making involves pearling of grains before milling. Pearling (also reported as debranning) is a treatment in which the outer layers are gradually removed from the cereal grain surface inwards by friction and abrasion (De Brier *et al.*, 2015). As the amount of aleurone layer remaining

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on the grains can be controlled, pearled wheat flour (PWF) with different nutritional profiles could be obtained by whole milling the pearled grains. PWF is assumed to contain large amounts of pentosans or dietary fibre derived from bran (Wang *et al*., 2019). Pearling is also a method able to reduce several contaminants, e.g. mycotoxins and heavy metals (Sovrani *et al*. 2012).

In conventional flour milling, the aleurone layer remains attached to the bran and is also removed with it, losing the nutritional value of the flour obtained. Pandiella *et al*. (2005) showed that 4–5% of pearling of wheat allows the aleurone layer to remain attached to the endosperm. Additionally, Mousia *et al*. (2004) found that wheat pearling before milling influences flour quality. However, little is known about the influence of pearled wheat flour on the nutritional profile and bread-making properties. Thus, the objective of this work was to evaluate the wheat pearling process as a strategy to reduce the detriment of whole-wheat flour over bread quality, and simultaneously to preserve some of the nutrients from the whole grain.

Experimental

Wheat sample, pearled grain processes and reconstitution of pearled wheat flour

Klein Rayo wheat grains (*Triticum aestivum*) were provided by the Instituto Nacional de Tecnología Agropecuaria (INTA, Marcos Juárez, Argentina). Wheat grains were tempered to 15.0% moisture for 24 h and processed as shown in Fig. 1. Wheat was pearled (rice polishing mill, Paz-1-1DTA, Zaccaria, Limeira, Brazil) in batches of 100 g with increasing pearling times (25, 125, 225 and 250 s) and a stone-to-screen gap of 4.5 mm was applied. For each time, three batches were pearled. Microscopy images of whole grains, pearled grains and their transversal section after 1 h of hydration were obtained by using a stereo microscope S8AP0 (Leica Microsystems Inc., Bannockburn, IL, USA). The resulting images were analysed using ImageJ v. 1.51j8 software to calculate and display shape descriptors, such as area, aspect ratio and circularity. The standard deviation and coefficient of variance of grain area were computed as an indicator of uniformity. Subsequently, pearled and whole grain samples were milled with a roller mill (Chopin Technologies CD1, Villeneuve-la-Garenne, France) and different streams (flour, coarse bran, fine bran and semolina) were reconstituted to obtain pearled wheat flour (P25s, P125s, P225s and P250s) and whole-wheat flour (WWF) respectively. WWF and refined flour (RF) of the same variety obtained by roller mill were used as a control. All flour samples were stored at −20 °C until further analysis. The chemicals used were all analytical grade. NaCl, sucrose and dry baker's yeast were purchased from the local market.

Characteristics of the flour sample

Hydrated particle size distribution was performed from 0.2 g of flour sample in aqueous suspension by laser light diffraction (Horiba LA 960, Kyoto, Japan). The d90 corresponding to the maximum diameter of 90% of the particles (% of total volume) and span which provide information on the amplitude and heterogeneity of the distribution were calculated. Moreover, colour was determined with the CIELAB system using a Minolta 508d colorimeter (Ramsey, NJ, USA). The coordinate L^* (lightness) was reported.

Flour was analysed for moisture, ash and protein content according to AACC Methods 44-15.02, 08-12.01 and 46-12.01 respectively (AACC, 2010). All the results were reported in terms of dry mass basis (% d.b.). Total starch, soluble (SDF), insoluble (IDF) and total dietary fibre (TDF) content were determined according to AACC Method 76-13.01 and AACC Method 32-07.01, respectively (AACC, 2010) (Total Starch Assay Kit and Total Dietary Fiber Assay Kit, Megazyme Ltd, Wicklow, Ireland).

Glutenin macropolymer (GMP) was isolated as described by Steffolani *et al*. (2010). The total protein content of GMP was determined using the Kjeldahl method (N × 5.7) (Method 46-12.01, AACC, 2010). The results were expressed as g GMP per g protein (dry mass basis).

The content of total (TP) and water-soluble pentosans (WSP) was quantified following the orcinol-HCl method modified by Steffolani *et al*. (2010) at 670 nm and were expressed in terms of dry basis.

Extraction for total polyphenols was performed using methanol:acetone:distilled water (30:30:40). The solvent mixture (1 mL) and flour samples (100 mg) were mixed for 5 min in the dark at 25 °C with continuous shaking and then centrifuged at 700 ***g*** for 10 min. This procedure was repeated three times. Free phenolic acids (FPA) were determined by the Folin–Ciocalteu method using gallic acid as a calibration standard according to Podio *et al*. (2017). The results were expressed as mg gallic acid equivalents per g flour (dry mass basis).

Ferulic acid (FA) was extracted according to Podio *et al*. (2017) with a slight modification. After alkaline hydrolysis and acidification treatment, the samples were centrifuged at 16 000 ***g*** for 20 min at 4 °C. Three millilitre of acetate ethyl was added to supernatant and mixed at 6000 ***g*** for 15 min. The ethyl acetate phase was recovered from the resulting multilayer system formed. This procedure was repeated to complete three ethyl acetate washes. Then, Na_2SO_4 was added to organic phase, stirred and kept for 1 h in the dark. Finally, the absorbance was read at 320 nm. FA concentration was calculated by linear regression using acid ferulic as standard and the results were expressed as μg FA per g flour (dry mass basis). All determinations were obtained in triplicate.

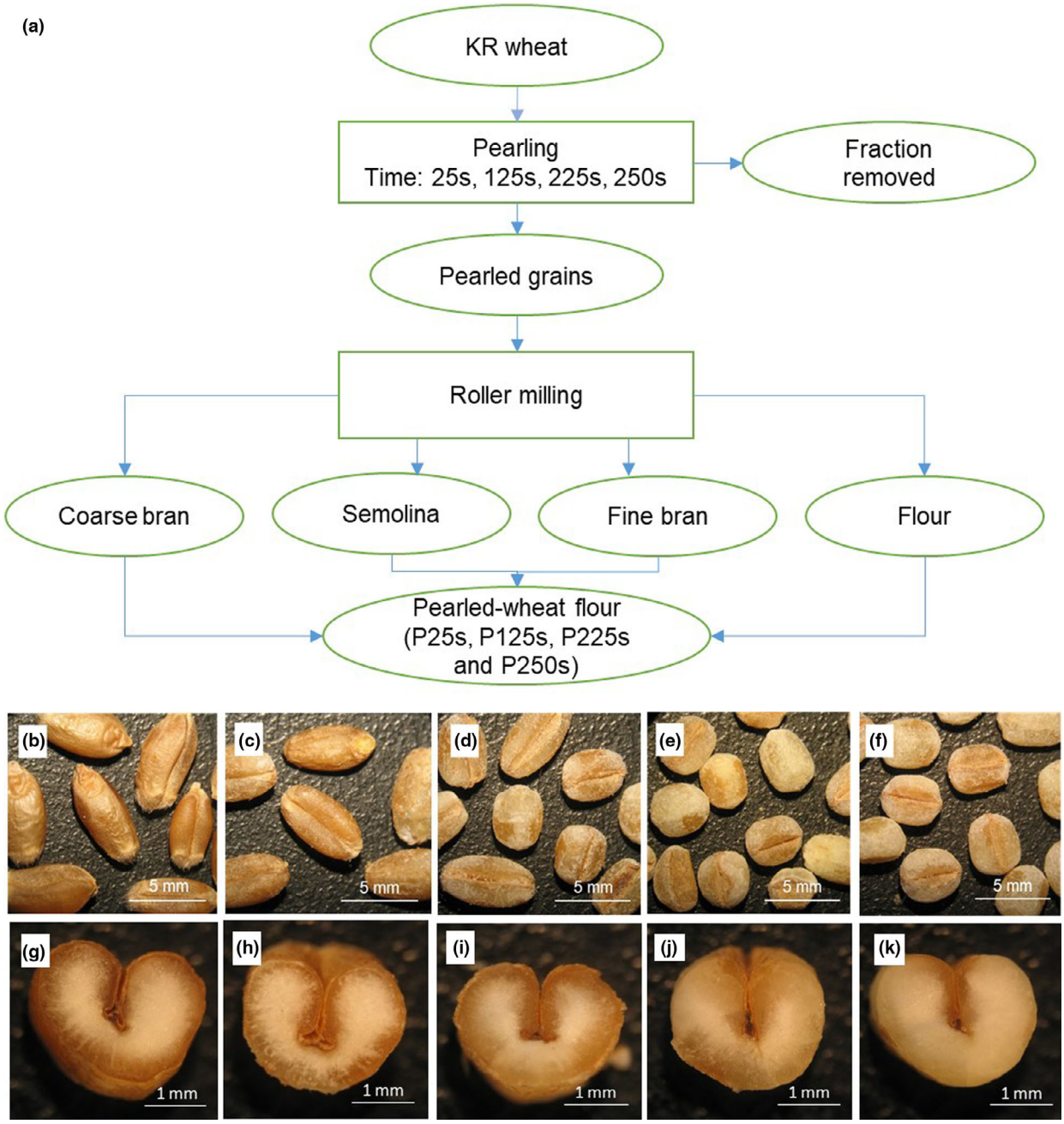

Figure 1 (a) Flow chart of Klein Rayo wheat milling and pearling process. Stereo-microscope images of non-pearled grains (b) and grains after increasing pearling time (c: P25s, d: P125s; e: P225s, f: P250s) and their respective transverse section (g, h, i, j, k).

Evaluation of rheological properties by Mixolab

The rheological properties of flour samples were carried out under controlled heating conditions (Chopin + protocol) in a Mixolab analyser (Chopin, Tripette et Renaud, Paris, France) according to the method 54-60.01 (AACC, 2010). The following Mixolab, dough parameters were determined: dough development time (DDT) that is the time necessary to reach the maximum torque (C1) at 30 °C, protein weakening (C2) that represents how much the dough consistency decreases due to shear and temperature stress, stability

(S) that refers to the time during which the upper frame is > C1 – 11%, maximum value (peak) of torsion during heating stage (C3), stability of hot starch paste (C4) and starch gelling (C5).

Bread-making procedure and bread quality

Microscale baking tests with 60 g of flour were carried out in triplicate for each flour sample according to Moiraghi *et al.* (2017) with minor modifications. The ingredients used were as follows: NaCl 1.5%; sucrose 1%; dry baker's yeast 3% (100% flour basis) and dough samples were prepared at optimum Mixolab water absorption. Four loaves were obtained for each bread-making procedure and the specific bread volume (SBV) was expressed as the volume/mass ratio ($cm^3\ g^{-1}$) of bread according to AACC method 10-05.01 (AACC, 2010) 2 h after baking. The textural profile analysis (TPA) of breadcrumb was determined by using an Instron Texture Analyzer (Universal Testing Machine Instron Model 3342, Canton, OH, USA). The loaves were evaluated at different times (2 and 72 h) in triplicate to determine the effect of storage time in poly bags at room temperature. At each time interval, two microscale bread were cut perpendicularly in half and crust ends were removed. The centre of each cross section (thickness 15 mm) was subjected to double compression–decompression cycles using a cylindrical probe (10 mm diameter) under the following conditions: 100 mm min^{-1} and 40% maximum deformation to obtain the characteristic curve of texture profile analysis. Moreover, the chromatic characteristics of the crust and bread crumb were determined with the CIELAB system using a Minolta 508d colorimeter (Ramsey, NJ, USA).

Statistical analysis

Results were obtained at least in triplicate, and the values were expressed as means ± the standard deviation. Univariate analysis of variance (ANOVA) was performed to better explain sample differences. The outcomes were compared by DGC means comparison test with a significance level of 0.05 (InfoStat, Facultad de Ciencias Agropecuarias, UNC, Córdoba, Argentina).

Results and discussion

Characterisation of pearled wheat

The selected pearling times (25, 125, 225 and 250 s) led to different pearling degrees removing the bran layer and endosperm; the yield of pearled wheat grains was about 95.6% (±0.26), 73.0% (±0.57), 61.5% (±0.72) and 59.1% (±0.35) (% of whole grain) respectively. Pearling effects on the morphology of wheat grains are shown in Fig. 1c–f. At longer pearling times, wheat grains turned spherical as the endosperm was partially removed (Fig. 1i–k); the flat surface of the ventral grain side was more prone to abrasion during pearling. Although the mechanical abrasion was homogeneous, the presence of the characteristic ventral crease in wheat hindered the entire bran layers removal as observed by Zanoletti *et al.* (2017). The analysis of grain shape allowed determining the effectivity of pearling process. In this sense, at longer pearling time, both surface area and aspect ratio of grain decreased with high level of uniformity (indicated by a coefficient of variance of grain area <10%), while the circularity values were the highest (Table S1).

Characterisation and proximal composition of flour samples

In general, both WWF and PWF exhibited a polymodal particle-size distribution with higher span values ranging from 11.59 (WWF) to 4.52 (P250s) (Figure S1). In WWF, many particles were larger than 1000 μm (d_{90} = 1534 μm). Milling of pearled grains showed a significant decrease in d_{90} (values varied between 925 and 559 μm), whereas RF presented a bimodal particle-size distribution from 13 to 185 μm (d_{90} = 186 μm) with the lowest span value (2.20). PWF showed slightly smaller particle sizes as observed by Lin *et al.* (2012) when the debranning degrees were over 2.5%. This might be as a result of removing material from the outer grain that affects the size, hardness and density of the grain.

Table 1 summarises the proximal composition and characteristic of flour samples. As expected, ash content reduced significantly with the progressive removal of external layers of wheat grain by pearling. Yet, ash content in the longest pearling time samples (P250s) did not come close to the characteristic values of RF, indicating that there are still bran layers attached to grains and consequently minerals as reported by Xue *et al.* (2014). In addition, L^* values of PWF were also significantly affected by their ash content (Table 1). However, as observed by Mousia *et al.* (2004), ash content and colour parameters of PWF with 5% of weight removal (P25s sample) were similar to those of WWF. As has been observed in Lin *et al.* (2012) at longer pearling times, L^* values of PWF tended to increase due to the reduction in pigmented bran tissues in the samples. Regarding PWF, a trend was observed to increase the total starch as the pearling time was increased, although it was only significant with respect to WWF. The protein content followed the opposite trend.

Weegels *et al.* (1996) studied glutenin macropolymer content in detail and reported firm evidence of a high positive correlation between GMP content in flour and bread volume. Although no significant differences were observed between the samples, the glutenin macropolymer-to-total

Table 1 Characteristic, nutritional composition and rheology of flour

	Samples flour					
Parameters	**WWF**	**P25s**	**P125s**	**P225s**	**P250s**	**RF**
Ash (%)	1.85 ± 0.09^{a}	1.62 ± 0.07^{b}	1.09 ± 0.04^{c}	0.89 ± 0.02^{d}	0.92 ± 0.01d	0.53 ± 0.01^{e}
*L**	82.9 ± 0.4^{d}	83.7 ± 1.0^{d}	88.0 ± 0.5^{c}	89.0 ± 0.1^{b}	89.5 ± 0.4b	91.0 ± 0.1^{a}
Total starch (%)	62.7 ± 1.2^{b}	71.6 ± 5.4^{a}	75.8 ± 1.9^{a}	78.0 ± 3.0^{a}	78.2 ± 0.4a	79.5 ± 1.1^{a}
Protein (%)	14.4 ± 0.3^{a}	14.7 ± 0.1^{a}	13.0 ± 0.1^{b}	12.6 ± 0.2^{c}	12.6 ± 0.1^{c}	13.7 ± 0.2^{b}
GMP/P (g GMP per g protein)	18.3 ± 0.5^{b}	21.7 ± 0.3^{a}	23.0 ± 0.8^{a}	23.8 ± 0.7^{a}	22.6 ± 0.3^{a}	20.4 ± 0.1^{b}
TDF (%)	15.04 ± 0.18^{a}	12.12 ± 0.69^{b}	8.48 ± 0.31^{c}	8.61 ± 0.24^{c}	8.87 ± 0.04^{c}	3.50 ± 0.80^{d}
IDF (%)	12.76 ± 0.57^{a}	10.85 ± 0.89^{b}	6.90 ± 0.21^{c}	7.16 ± 0.18^{c}	6.25 ± 0.27^{c}	1.98 ± 0.11^{d}
SDF (%)	2.28 ± 0.38^{a}	1.26 ± 0.20^{b}	1.59 ± 0.11^{b}	1.45 ± 0.06^{b}	2.62 ± 0.23^{a}	1.52 ± 0.69^{b}
TP (%)	9.29 ± 0.17^{a}	7.77 ± 0.16^{b}	5.01 ± 0.22^{e}	5.42 ± 0.13^{d}	5.45 ± 0.11^{c}	3.34 ± 0.07^{f}
WSP (%)	1.72 ± 0.07^{a}	1.48 ± 0.02^{b}	1.33 ± 0.00^{c}	1.63 ± 0.07^{a}	1.73 ± 0.05^{a}	1.13 ± 0.02^{d}
WSP/TP (g WSP per g 100 TP)	18.5 ± 1.1^{c}	19.0 ± 0.1^{c}	26.6 ± 1.2^{b}	25.6 ± 1.6^{b}	25.1 ± 1.1^{b}	33.9 ± 0.2^{a}
FPA (mg GAE per 100 g)	148.7 ± 1.9^{a}	146.6 ± 0.3^{a}	136.7 ± 1.0^{b}	138.4 ± 2.1^{b}	130.0 ± 0.4^{c}	129.5 ± 3.2^{c}
FA (μg FA g^{-1})	1142 ± 99^{a}	926 ± 147^{a}	587 ± 102^{b}	517 ± 80^{b}	495 ± 15^{b}	218 ± 3^{c}
	Samples dough					
WA (g per 100 g)	71.2 ± 0.0^{a}	68.9 ± 0.3^{b}	66.7 ± 0.3^{c}	66.3 ± 0.1^{c}	66.0 ± 0.0^{c}	59.0 ± 1.1^{d}
DDT (min)	7.67 ± 0.30^{b}	8.44 ± 0.05^{a}	8.35 ± 0.10^{a}	8.28 ± 0.11^{a}	8.27 ± 0.07^{a}	5.9 ± 0.14^{c}
S (min)	1.77 ± 0.12^{b}	1.25 ± 0.05^{c}	1.80 ± 0.05^{b}	1.58 ± 0.15^{b}	1.56 ± 0.00^{b}	4.30 ± 0.02^{a}
C2 (Nm)	0.46 ± 0.00^{b}	0.47 ± 0.01^{b}	0.48 ± 0.01^{b}	0.51 ± 0.03^{a}	0.53 ± 0.01^{a}	0.47 ± 0.02^{b}
C3 (Nm)	1.60 ± 0.00^{a}	1.63 ± 0.01^{a}	1.60 ± 0.02^{a}	1.61 ± 0.01^{a}	1.63 ± 0.04^{a}	1.55 ± 0.03^{b}
C4 (Nm)	1.22 ± 0.04^{b}	1.25 ± 0.00^{b}	1.31 ± 0.02^{a}	1.31 ± 0.01^{a}	1.36 ± 0.04^{a}	1.32 ± 0.03^{a}
C5 (Nm)	2.05 ± 0.03^{a}	2.09 ± 0.03^{a}	2.16 ± 0.03^{a}	2.13 ± 0.02^{a}	2.20 ± 0.02^{a}	2.24 ± 0.11^{a}

Values are expressed on a dry mass basis (% d.b.). Mean values in the same row followed by different superscript letters are significantly different ($P < 0.05$).

C2, protein weakening; C3, maximum value (peak) of torsion during heating stage; C4, stability of hot starch paste; C5, starch gelling; DDT, dough developing time; FA, ferulic acid; FPA, free phenolic acids; GMP/P, glutenin macropolymer to total protein ratio; IDF, insoluble dietary fibre; *L**, lightness; S, stability of dough; SDF, soluble dietary fibre; TDF, total dietary fibre; TP, total pentosans; WA, water absorption; WSP/TP, water-soluble pentosans to total pentosans ratio; WSP, water-soluble pentosans.

protein ratio (g GMP per g P) was significantly higher in P125, P225 and P250s samples in relation to RF. A lower proportion of non-GMP protein could result in stronger gluten matrix and also indicate better bread-making performance as observed in Zhong *et al*. (2018)

Nutritional flour composition

Analysis of TDF and IDF produced result that was in line with expectations. The decrease in fibre content was also observed by Zanoletti *et al*. (2017) and Tosi *et al*. (2018) at different levels of pearled grains. WWF and PWF had higher content of TDF and IDF than the RF respectively. Even at longer pearling times, the samples preserved twice the TDF compared to RF. Consequently, this significant decrease in IDF was reflected in an increase in SDF proportion at the P250s pearled flour as compared to RF. Considering that aleurone contains between 45% and 50% total dietary fibre (Amrein *et al*., 2003), presumably all pearled flour contained remnants of the aleurone layer.

Wheat quality is not only determined by its most widely found components but also by non-starchy polysaccharides (arabinoxylans or pentosans), since they play a particularly important role in the quality of wheat-based products (Wang *et al*., 2019), and also having multiple health benefits (Slavin *et al*., 2001). In general, at longer pearling time, TP decreased. Specifically, a considerable reduction in water-insoluble pentosans (WISP) was seen, while WSP content remained relatively constant. This change in the proportion of WISP was also evidenced in a higher WSP/TP ratio. Considering that WSP are mainly concentrated in the aleurone layer, and that WISP are found in greater concentration in the outer layers (Bucsella *et al*., 2016), the low variability of WSP content among PWF could indicate that some aleurone layer cells remain in the samples despite the pearling time applied. P225s and P250s samples equalled the WSP content of WWF and showed a 40–50% higher WSP content than RF (Table 1). Additionally, as proposed by Steffolani *et al*. (2010), WSP in this pearled wheat flour could play a major role in enhancing bread quality by the

high viscous and gelling property, thus improving the strength of gluten and the stabilisation of the gas cell.

Free phenolic acids varied slightly between WWF and RF. Although phenolic compounds of WWF are mainly concentrated in the cell walls of the outer layers of the grain (Beta *et al.*, 2005), WWF also contains starchy endosperm that dilutes the concentration of polyphenolic compounds. FPA content tended to slightly decrease when removal advanced towards the innermost layers of the wheat grain, as reported by Beta *et al.* (2005). The presence of the pericarp and aleurone layers significantly enhanced the FPA of the PWF as compared to those of the RF, except for the P250s sample that contained the same concentration of RF. Therefore, the pearling time of wheat grains could be regulated to obtain flour enriched with bioactive compounds.

Among the wide variety of phenolic compounds, FA is the most abundant in wheat and found principally in bound form. Mateo Anson *et al.* (2008) concluded that the antioxidant potency of wheat grain by-products is related to the aleurone layer content, which can be attributed to the presence of large amounts of FA. The concentration in WWF was 1142 μg FA g^{-1} and varied from 495 to 926 μg FA g^{-1} in the PWF. Similarly, Martini *et al.* (2015) noticed a decrease in FA bound by increasing the removal of external layers richer in fibre where most of bound phenolic acid are found. In the present study, a marked decrease can be seen in ferulic acid content between P25s and P125s pearled flour. Nevertheless, in P125s, P225s and P250s samples, FA content was two- and threefold higher as compared to RF (218 μg FA g^{-1}). Regardless of the pearling time applied, remaining layers of bran rich in FA content were preserved due to the presence of crease.

Rheological properties

The absorption of water (WA) was influenced by the pearling process (Table 1), and it decreased following reduction in TP and TDF. According to Hemdane *et al.* (2016), hydration is induced by hydroxyl groups in the fibre structure of WWF, which allows bind water through hydrogen bonds during the mixing process. As expected, all pearled wheat dough exhibited longer development times (DDT), 40% higher compared to RF dough, mainly due to its major total fibre content. Additionally, whole-wheat dough and pearled wheat dough also showed a stability lower than that of the refined wheat dough, breaking down between 1 and 2 min. Protein weakening parameter (C2) is associated with flour protein quality, which in turn affects dough quality. Noort *et al.* (2010) reported changes in dough stability and higher dough weakening in fibre-enriched wheat dough, as a consequence of gluten-diluting effect. C2 values were significantly higher in P225s and P250s dough samples. The major capacity of the gluten network of these dough samples, which partially prevents mechanical and thermal protein weakening, could be attributed to the higher proportion of GMP. During the heating period, all pearled wheat dough showed a similar C3 torque value as whole-wheat dough. C4 and C5 parameters, which provide information about the hot-gel stability and starch gelling, were not influenced by the increase in pearling time (Table 1).

Impact of pearling process on bread quality

Figure 2 shows the impact of the pearling time of wheat grains on bread quality. PWB evidenced higher SBV than WWB ranging from 3.1% to 14.9%. PWB made with P250s sample showed the highest increase in volume (Table 2). The formation of the gluten network was negatively influenced by the presence of TDF and IDF, including TP, as revealed by the Mixolab data. As a result, SBV was low when samples had high content of these components. However, the TDF content of pearled flour was considerably higher when compared with RF; 125 s of pearling was enough to remove the outermost layers of the bran (outer pericarp and epicarp hairs), which affect baking performance detrimentally. WSP mainly found in aleurone layer have a positive effect on bread-making in contrast to WISP, mostly found in the outer layer and having adverse effect on the dough and end-product properties by disrupting the cell wall film (Bucsella *et al.*, 2016).

In the present work, no relationship was found between WSP and SBV in a comparison with controls. Nevertheless, SBV was higher when flour samples had higher WSP/TP ratio. This could be considered favourable for bread-making quality, especially for those pearled samples having a lower WISP content (P125s and P225s). As predicted by Mixolab test, higher C2 torque values in P225s and P250s samples led to better bread-making performance due to the development of gluten matrix with fewer non-GMP protein by increasing GMP proportion (g GMP per g protein) at longer pearling times. Therefore, the pearling process slightly improved the bread-making performance of samples.

A decrease in bran content and polyphenolic compounds in pearled wheat flour (P125, P225s and P250s) led to a colour removal, an increase in lightness and a decrease in the browning of both crumb and crust of the bread compared to bread made with WWF (Fig. 2). These results agreed with those reported by Lin *et al.* (2012) on steamed bread with different flour pearling degrees.

The hardness of fresh bread ranged from 1.48 to 2.54 N (Table 2). Although crumb hardness on day 3 in pearled wheat bread samples was 6–12 times greater than that seen initially, bread crumb was, interestingly,

Figure 2 Representative images of microscale bread made with whole-wheat flour (WWB), pearled-wheat flour (PWB) and refined flour (RFB).

Table 2 Bread quality parameters

		PWB				
Parameters	**WWB**	**P25s**	**P125s**	**P225s**	**P250s**	**RFB**
SBV ($cm^3\ g^{-1}$)	1.95 ± 0.04^{d}	2.01 ± 0.01^{d}	2.11 ± 0.02^{c}	2.15 ± 0.02^{c}	2.24 ± 0.01^{b}	2.37 ± 0.06^{a}
Browning crust (100-L^*)	40.1 ± 0.6^{a}	41.7 ± 0.1^{a}	35.0 ± 1.6^{b}	33.1 ± 1.4^{b}	36.0 ± 0.7^{b}	28.6 ± 0.3^{c}
Browning crumb (100-L^*)	48.2 ± 1.0^{a}	45.7 ± 0.6^{a}	40.0 ± 1.3^{b}	39.8 ± 0.3^{b}	40.1 ± 0.7^{b}	28.6 ± 1.5^{c}
Hardness Day 0 (N)	2.41 ± 0.27^{a}	2.54 ± 0.02^{a}	1.49 ± 0.18^{b}	1.88 ± 0.03^{b}	1.48 ± 0.03^{b}	2.50 ± 0.34^{a}
Hardness Day 3 (N)	14.4 ± 2.2^{b}	15.4 ± 4.7^{b}	19.2 ± 0.9^{b}	17.2 ± 2.1^{b}	17.9 ± 0.7^{b}	27.4 ± 5.8^{a}

Specific bread volume, browning of crust and breadcrumb (100-L^*) and firmness of breadcrumb on day 0 and day 3. Different letters in the same row indicate significant differences ($P < 0.05$).

less hard than that of refined flour bread (RFB). In addition, RFB showed the highest hardness values at day 3 of the storage. As explained by Steffolani *et al.* (2010), pentosans are characterised by the ability to retain water and form viscous solutions or gels by covalent bonds, affecting the water distribution between the constituents of the dough, thus, the speed of staling of the bread is modified. Additionally, chewiness values (data not shown) representing work required to break down food until ready to be swallowed (Hleap & Velasco, 2010) were consistent with hardness patterns. Adhesiveness and cohesiveness (data not shown) did not show significant differences between samples. The lower hardness values of different PWB could be attributed to the higher TDF as compared to RFB. The presence of a considerable amount of fibre in bread formulation prevents bread from water loss due to its water holding capacity and thereby affecting the speed and magnitude of amylopectin retrogradation (SchleiBinger *et al.*, 2013; Mellado & Haros, 2016). For RFB consumers, texture and colour are important characteristics for its acceptance. Thus, the acceptance of pearled wheat bread (especially, P125s, P225s and P250s) could be encouraging as the increasing pearling times led to lighter crust and crumb colour and significantly increased specific bread volume compared to WWB.

Conclusions

Wheat pearling process resulted in pearled wheat flour which kept several nutritional attributes of whole grain such as considerably higher content of FPA, FA, WSP and TDF in relation to refined flour. The nutritional profile of these types of pearled wheat flour could be appreciated by those consumers who have traditionally preferred refined flour bread. Moreover, this process has allowed to obtain pearled wheat flour which overcomes the detrimental effects of whole-wheat flour in end-products, granting them characteristics similar to those of refined flour bread. Pearled wheat flour, especially P125s, P225s and P250s samples, was suitable for bread-making, as they produced high specific volume bread with lighter colour crumb and crust as compared to WWB, and lower breadcrumb hardness as compared to RFB. The quality improvement was due to the extraction of the outer layers of the bran and decrease in insoluble dietary fibre which are both causes of detriment on bread quality. Also, pearling process increased the proportion of high molecular weight glutenins (g GMP per g protein) favouring the development of a better gluten network.

Slight improvements in the pearling process to recover the removed endosperm would enable to

achieve a high yield of pearled wheat. Moreover, optimisation of this process would enhance the nutritional profile of flour by increasing the content of aleurone layer. Thus, pearling process represents an economical and feasible alternative that could be applied in the milling industry.

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Conflict of interest

The authors declare that there are no conflict of interest.

Author contribution

José L. Navarro: Investigation (equal); Writing-original draft (equal). **Camila Biglione:** Investigation (equal). **Candela Paesani:** Investigation (equal). **Malena Moiraghi:** Methodology (equal). **Alberto E. León:** Methodology (equal); Supervision (equal). **M. Eugenia Steffolani:** Conceptualization (equal); Formal analysis (equal); Supervision (equal); Writing-review & editing (equal).

Ethical approval

Ethics approval was not required for this research.

Peer review

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Data availability statement

Research data are not shared.

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De Brier *et al*. characterised the pearlings and bran obtained by subsequently roller milling pearled wheat kernels. This study provides information about how the pearling process affects the milling performance and details the main factors that negatively alter wholewheat bread. Also, this study stated that homogeneous removal of outer layers due to pearling did not impact the tissues in the crease.

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This article investigates the hydration properties reducing agents' content and bran-associated enzyme activities of ground bran and bran pearling fractions to understand the impact on bread-making. In their research the authors suggest that bran hydration properties and enzymatic load affect the bread-making. Hemdane *et al*. results are in accordance with our research, which could explain rheological properties and bread-making performance of pearled wheat flour obtained in the present manuscript.

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The mentioned study provides a theoretical basis for the exploitation of water-extractable arabinoxylan as a nutritious and technofunctional dough improver. Then, this article represents an important contribution to our research, due to which it was possible to assume that the large amount of pentosans contained in pearled wheat flour could play a particularly important role in the bread-making performance.

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Supporting Information

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

Figure S1. Particle-size distribution of flour samples. Whole-wheat flour (WWF), pearled-wheat flour by 25, 125, 225, and 250 s of pearling (P25s, P125s, P225s, and P250s), and refined flour (RF).

Table S1. Grain-shape analysis.