LWT - Food Science and Technology 133 (2020) 110067

Contents lists available at ScienceDirect

LWT

journal homepage: www.elsevier.com/locate/lwt

Improving roller milling technology using the break, sizing, and reduction systems for flour differentiation

Alessio Cappelli *, Marco Mugnaini, Enrico Cini

Department of Agriculture, Food, Environment and Forestry (DAGRI), University of Florence, Piazzale delle cascine 16, 50144, Florence, Italy

ARTICLE INFO

Keywords:
Mill optimisation
Wheat grinding
Dough rheology
Bread
Innovations in milling.[1]

ABSTRACT

A key issue in breadmaking is to select the optimal milling strategy, as this has a significant impact on the quality of flour. Therefore, this work assesses if flour recovered from: (i) the break system, and (ii) the sizing and reduction system of the roller mill differ from control flour. Differences in flour yield, flour composition, dough rheology, and bread characteristics for an ancient cultivar (*Conte Marzotto*) and a modern cultivar (*Nogal*) were evaluated. For break system flour, lower fibre and higher starch content were found. Sizing and reduction system flours had higher fibre and phenolic content, and lower starch. Moreover, dough stability was higher for break system flour and, in the case of *Nogal*, a significant increase in bread specific volume was found. These results highlighted that the proposed strategy can be effective in producing diverse flours for different markets (e.g. consumers and bakers). In particular, break system flours have better rheological performance and improved bread characteristics, while sizing and reduction system flours have a more interesting nutritional profile. Further advantages of the method include its ease of application, no additional expenditure, no lengthening of milling time, increased profits, better product differentiation, and the expansion of the potential clientele.

1. Introduction

Grain milling might be the oldest manufacturing process in the world. This essential activity produces flour, a basic ingredient in many foods (Cappelli et al., 2018; Kweon, Slade, Levine, & Gannon, 2014). Although many techniques are used in the food industry, roller and stone mills are the most widely used (Doblado-Maldonado, Pike, Sweley, & Rose, 2012; Cappelli, Oliva, & Cini, 2020). Selecting the optimal milling strategy is essential, as it has a significant influence on the quality of wheat flour, dough rheological properties, and bread characteristics (Doblado-Maldonado et al., 2012; Cappelli, Oliva, & Cini, 2020; Pagani, Marti, & Bottega, 2014). Several authors have highlighted other factors that influence the quality of the final product. They begin with responsible management of agronomical treatments that improve the technological properties of flour (Guerrini et al., 2020; Migliorini et al., 2016) and reduce environmental pressures (Recchia, Cappelli, Cini, Garbati Pegna, & Boncinelli, 2019; Fusi, Guidetti, & Azapagic, 2016); to the careful selection of the milling method (Cappelli, Guerrini, Parenti, Palladino, & Cini, 2020; Kihlberg, Johansson, Kohler, & Risvik, 2004; Pagani et al., 2014); and the kneading process (Cappelli, Canessa, & Cini, 2020; Cappelli, Guerrini, Cini, & Parenti, 2019; Parenti, Guerrini, Cavallini, Baldi, & Zanoni, 2020).

Concerning to the milling method, although stone milling is still preferred by artisanal bakers and organic food producers who appreciate its effects on flour, dough, and bread, not to mention the marketing advantage related to the use of the term “stone ground” on products, the food industry prefers roller milling (Cappelli, Oliva, & Cini, 2020). This is because the latter has several production advantages. They include higher efficiency and flexibility (Doblado-Maldonado et al., 2012), lower heat generation, an optimal falling number, and better dough rheology (Kihlberg et al., 2004). Although roller mill technology has been significantly improved over time, few articles have been published that compare the stone mill and the roller mill from a usability point of view (Cappelli, Oliva, & Cini, 2020). This gap in the literature is difficult to understand, given that usability has become a key element in food processing and factory development (Cappelli, Parretti, Cini, & Citti, 2019). In particular, emerging production chains, such as those that use insects (Cappelli, Cini, Lorini, Oliva, & Bonaccorsi, 2020; Roncolini

---

Abbreviations: Break system flour, B; Sizing and reduction system flour, SR; Control flour, C; Dough tenacity, P; Dough extensibility, L; Index of swelling, G; Deformation energy, W; Curve configuration ratio, P/L; Water absorption, WA; Dough development time, DDT; Dough stability, S; Degree of softening, DS; Twenty minute drop, TMD.

* Corresponding author.
E-mail address: alessio.cappelli@unifi.it (A. Cappelli).

https://doi.org/10.1016/j.lwt.2020.110067
Received 14 May 2020; Received in revised form 2 July 2020; Accepted 13 August 2020

et al., 2020), need new machines and plants, particularly for the milling process, which represents a critical issue.

The machine–product interaction, and its effects on the final product is particularly relevant in wheat milling (Cappelli, Oliva, & Cini, 2020; Cappelli, Guerrini, et al., 2020). Although the roller mill has been significantly improved from a technological point of view, much can still be done. Earlier works highlighted various interesting strategies, notably: wheat debranning (pre-milling) combined with the processing of bran and middlings (Cappelli, Oliva, & Cini, 2020); the correct management of wheat conditioning (Cappelli, Guerrini, et al., 2020) and of differential ratios; and the development of fully automated, adaptive mills (Cappelli, Oliva, & Cini, 2020). Although these solutions are appealing, another important issue is whether flour obtained from different pairs of rollers differs in terms of its nutritional content and technological properties.

The typical roller mill is divided into three systems. The first is the break system, which separates endosperm from bran and germ by opening the kernel and scraping off the bran from the endosperm (Posner, 2003; Rosentrater & Evers, 2017). Although some flour is produced, that is not the purpose of this stage (Rosentrater & Evers, 2017). The second is the sizing system; here the purpose is to scrape bran particles from the endosperm before further processing (Rosentrater & Evers, 2017). The third is the reduction system; here the goal is to crush and shear the endosperm until the flour meets a defined refinement standard (Rosentrater & Evers, 2017). To the best of the authors' knowledge, there are no studies that assess or compare differences between flours obtained by the break, sizing, and reduction systems, thus motivating this work. Therefore, the aim of this study is to assess if flour recovered from the break system, and the sizing and reduction system, differ between them and from control flour, obtained at the end of the complete milling process. We examined two wheat cultivars: an ancient wheat (*Conte Marzotto*) and a modern wheat (*Nogal*) and assessed differences in flour yield, flour composition, dough rheological properties, and bread characteristics.

2. Materials and methods

2.1. Raw materials, milling process, and flour preparation

Investigations were carried out on two wheat cultivars, an ancient wheat (*Conte Marzotto*) and a modern wheat (*Nogal*), kindly provided by Molino Cicogni (Arezzo, Italy). The former is widely cultivated in Italy while the latter is widely cultivated in Europe. Grain was purified before conditioning, and left to stand for 24 h before milling. The milling process used a roller mill (G.L.D., Golfetto Sangati Ltd., Padova, Italy) installed at the Molino Cicogni factory in Italy, with a production capacity of 30 tons/day. As shown in Fig. 1, the break system is composed of two pairs of rollers (B1 and B2), and the sizing and reduction system consists of three pairs of rollers (C1, C2, and C3). After each passage between a pair of rollers, the milled material is sent to the respective section of the plansifter (Fig. 1). The section B1 of the plansifter is composed, in order, by six 300 μm sieves, followed by four 200 μm sieves, and finally by six 125 μm sieves. The section B2 of the plansifter is composed by six 260 μm sieves, followed by four 200 μm sieves, and finally by six 100 μm sieves. With respect to the section C1 of the plansifter, the milled material is sieved through four 160 μm sieves and six 100 μm sieves. The section C2 of the plansifter is composed by four 160 μm sieves and by six 100 μm sieves. Finally, the section C3 of the plansifter is composed by three 200 μm sieves and by six 100 μm sieves.

The experiment used 100 kg of wheat for each cultivar. The refined flour obtained from each step (B1, B2, C1, C2, and C3) was collected from the respective part of the plansifter, weighed, and used to determine the total percentage yield needed to prepare the three tested flours. Three samples, each weighing 2.7 kg, were prepared for both *Conte Marzotto* and *Nogal*, as follows: the first, used the flour obtained by the break system (B1 + B2); the second, used the flour obtained by the sizing and reduction system (C1 + C2 + C3); and the third, control sample, used flour obtained by the complete milling process (B1 + B2 + C1 + C2 + C3). Fresh brewer's yeast (Zeus, Zeus IBA Ltd., Florence, Italy), salt (Chantesel Ltd.), and water (Acqua minerale San Benedetto Ltd.) were purchased in a local supermarket.

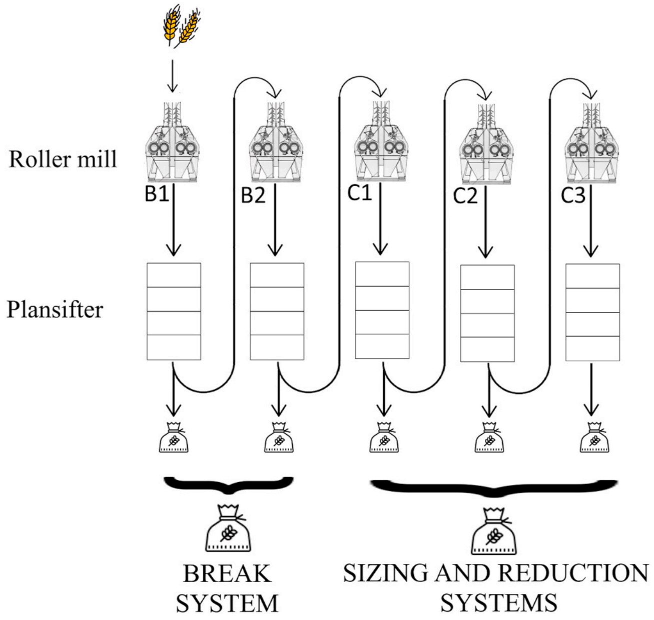

Fig. 1. Schematic representation of the roller mill used in trials.

2.2. Experimental design

Our experiment evaluated differences between flour, dough, and bread, as a function of the part of the roller mill system used to produce the refined flour. Flours obtained from the break system, the sizing and reduction system, and at the end of the complete milling process (control), were compared for both *Conte Marzotto* (ancient wheat) and *Nogal* (modern wheat). Three flours (for each cultivar) were prepared according to the percentages reported in Table 1. Break system flour (B) was obtained by the recombination of flours recovered from B1 and B2 channels. Sizing and reduction system flour (SR) was obtained by the recombination of flours from C1, C2, and C3 channels. Finally, a control flour (C), representative of the complete milling process, was obtained by the recombination of flours from all mill channels. The percentages reported in Table 1 were determined according to milling yield. Following the procedure described in ISO 27971, total kneading time was set at eight minutes in Chopin alveograph tests (ISO, 2008), and 20 min for breadmaking tests. All tests were carried out in three replicates.

2.3. Flour characterisation and analysis

Protein (AOAC 920.87 (AOAC International, 2005)), total dietary

Table 1
Percentages of recovered flours used in the preparation of tested flours.

Flour sample	B1 (%)	B2 (%)	C1 (%)	C2 (%)	C3 (%)
Conte Marzotto control	26.84	7.45	33.25	21.57	10.89
Conte Marzotto break system	78.27	21.73	–	–	–
Conte Marzotto sizing and reduction system	–	–	50.60	32.83	16.57
Nogal control	18.38	7.94	31.90	23.50	18.28
Nogal break system	69.84	30.16	–	–	–
Nogal sizing and reduction system	–	–	43.29	31.89	24.82

fibre content (AOAC 991.43 (AOAC International, 2005)), starch (AOAC 979.10 (AOAC International, 2005)), ash (AOAC 923.03 (AOAC International, 2005)), and total phenolic content (AOAC SMPR 2015.009 (AOAC International, 2005)), were determined by the Analytical Food Laboratory (Florence, Italy) following approved, official methods.

2.4. *Rheological properties of doughs*

Differences in the rheological properties of doughs obtained with the three tested flours (B, SR, and C) were evaluated with a Chopin NG alveograph linked to an alveolink integrator–recorder (Chopin technologies, Villeneuve-La-Garenne, France), and a farinograph (Brabender, Duisburg, Germany) in three replicates. Consistent with the procedure described in ISO 27971 (ISO, 2008), dough tenacity (P), dough extensibility (L), deformation energy (W), the index of swelling (G), and the curve configuration ratio (P/L) were evaluated. Farinograph trials followed the ICC 115/1 method from the International Association for Cereal Science and Technology (International Association for Cereal Chemistry, 1992). Here, water absorption (WA), dough development time (DDT), dough stability (S), degree of softening (DS), and the twenty minute drop (TMD) were assessed.

2.5. *Breadmaking*

The straight dough method was applied. Mixing, dough formation, resting, leavening with fresh brewer's yeast and baking, were performed using a bread machine (Pain Dorè, Moulinex, Ecully, France). The recipe was as follows: 310 g of wheat flour, 13 g of brewer's yeast, 9 g of salt, and a variable amount of water according to water absorption percentages recorded in farinograph trials. Optimum amounts of water for *Conte Marzotto* were: 49.60% for C; 47.93% for B; and 49.77% for SR. In the case of *Noga*l, these amounts were: 51.77% for C; 51.60% for B; and 51.47% for SR. The amount of water added in breadmaking is referred to the flour amount (310 g) and not to the sum of the ingredients. Kneading was carried out at 110 RPM at 20 °C for 20 min. Resting, fermentation, and proofing were performed at 40 °C for 93 min. Finally, baking was carried out at 180 °C for 48 min. After baking, breads were cooled to room temperature and stored in paper bags, following current practice.

2.6. *Bread analysis*

The standard millet displacement method (AACC, 2000) was used to measure bread specific volume (L/kg), consistent with earlier work (Cappelli, Guerrini, et al., 2019; Parenti et al., 2020). Bread loaf height (mm) was measured with a calliper at the centre of the loaf. Crumb density (g/ml) was determined from the mass/volume ratio. Crumb and crust moisture (g/100 g) were determined by gravimetry at 105 °C until a constant weight was reached.

2.7. *Statistical analysis*

Data were assessed with a non-parametric test. In particular, the Wilcoxon-Mann Whitney rank-sum test was applied, consistent with earlier work (Cappelli, Oliva, Bonaccorsi, Lorini, & Cini, 2020). Significance was set at $p < 0.05$. The statistical analysis was carried out using R software (version 3.6.1).

3. Results and discussion

3.1. *The milling process*

Figs. 2 and 3 report yield for the cultivars *Conte Marzotto* and *Nogal*, respectively. Furthermore, Table 1 shows the percentages of flour from each pair of rollers used in the preparation of the three tested flours (B, SR, and C). Figs. 2 and 3 show that yields were similar for break, and sizing and reduction systems. Regarding the break system, yield was highest in the first stage (B1) for both cultivars. Yield in the B1 channel was lower for *Nogal* than *Conte Marzotto* (18.38% versus 26.84%). This reflects the greater hardness and resistance to milling of the modern cultivar with respect to the ancient cultivar (Migliorini et al., 2016; Posner, 2003). This distinction disappeared in the second stage (B2), where yield was very similar for the two cultivars. Moreover, the differences in size or shape between wheat kernels, might be another reason which affected the flour yields.

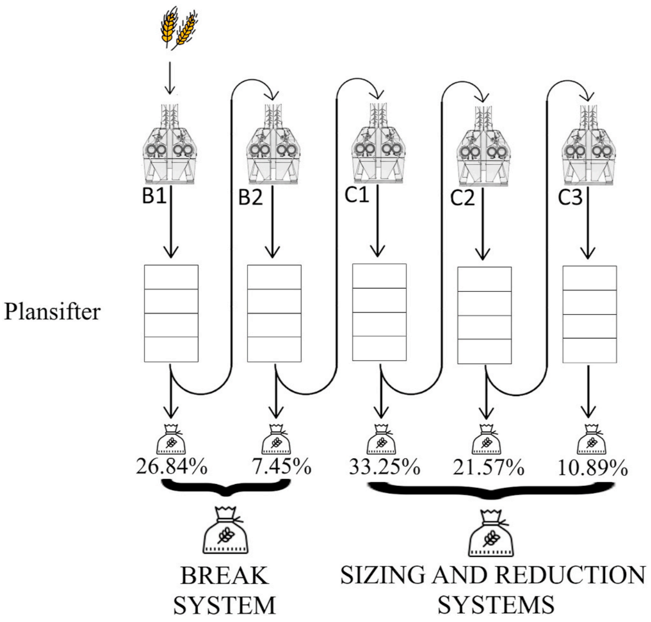

Fig. 2. Yield for the *Conte Marzotto* cultivar.

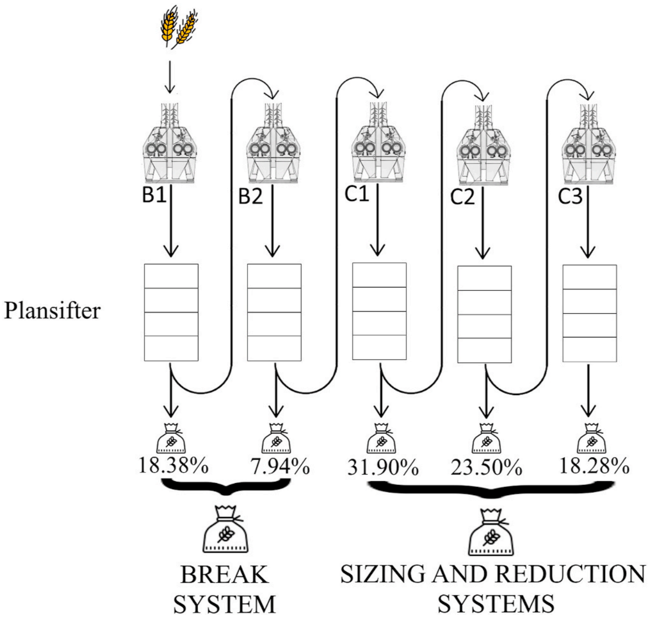

Fig. 3. Yield for the *Nogal* cultivar.

Turning to the sizing and reduction system, yield was similar for C1 and C2 channels, for both cultivars. However, for the C3 channel, yield was higher for *Nogal* than *Conte Marzotto* (18.28% versus 10.89%). This result highlights that exposing the modern wheat cultivar to several milling stages increases refined flour yield and reduces by-products.

3.2. *Compositional analyses of flour*

The results of compositional analyses are shown in Table 2. For both cultivars, B flours are characterized by lower total dietary fibre and higher starch content, compared to both C and SR flours. On the other hand, SR flours has higher total dietary fibre and phenolic content, and lower starch content compared to B and C flours. This result could be related to the aim of the milling step and the characteristics of the rollers used in break, and the sizing and reduction system, as reported in earlier work (Cappelli, Oliva, & Cini, 2020). The slightly higher total phenolic content observed in SR flours could be attributed to the higher total dietary fibre content that is derived mainly from non-endospermic kernel components, as this is where the majority of phenolic compounds are found (Doblado-Maldonado et al., 2012). No noteworthy differences were found for other compositional parameters.

3.3. *Dough rheological tests*

3.3.1. *Farinograph*

The results of farinograph tests are reported in Table 3. With respect to water absorption (WA) the results of the Wilcoxon-Mann Whitney rank-sum test do not show any statistically significant difference between the tested samples in both cultivars. Nevertheless, the figures reported in Table 3 show that, in the case of *Conte Marzotto*, B flour had lower WA compared to both C and SR flours. This is due to the statistically-significant relationship between WA and protein ($p < 0.001$) highlighted in earlier work (Cappelli, Oliva, et al., 2020). Moreover, studies by Finney, Yamazaki, Youngs, and Rubenthaler (1987), Ma et al. (2007) and Kucek et al. (2017), confirm that lower protein content is related to lower WA.

Another important factor which influence WA and several others rheological parameters is the gluten quantity and quality. As widely reported in the literature, modern wheat varieties are characterized by higher protein (and gluten) content and by stronger gluten network (De Santis et al., 2017; Cappelli, Canessa, & Cini, 2020). The latter is due to a lower gliadins/glutenins ratio (i.e. higher glutenin content), improved glutenin allelic composition (due to the introduction of high-quality alleles at the Glu-B1 and Glu- B3 loci), and the differential expression of specific storage proteins (De Santis et al., 2017; Cappelli, Canessa, & Cini, 2020). The results reported in Table 3 support these considerations, showing lower WA in the case of *Conte Marzotto* B flour compared to both C and SR flours, and compared to *Nogal* flours. Total dietary fibre content also influences WA; the high water retention capacity of fibre is due to the higher number of hydroxyl groups (Gómez, Jiménez, Ruiz, & Oliete, 2011). Moreover, arabinoxylans, inulin, and β-glucans increase WA and have negative effects on gluten development, dough rheology, and bread characteristics (Cappelli, Guerrini, et al., 2019; Gómez et al., 2011; Doblado-Maldonado et al., 2012). Arabinoxylans, in particular, affect dough rheology and bread characteristics by binding water, increasing viscosity, and disturbing the formation of the protein network during kneading (Cappelli, Guerrini, et al., 2019; Gómez et al., 2011; Doblado-Maldonado et al., 2012). In the case of *Conte Marzotto* B flour, lower WA might be due to both lower protein and lower total dietary fibre content.

Table 2
Results of flour characterisation and analyses.

Flour sample	Starch (g/100 g)	Protein (g/100 g)	Total dietary fibre (g/100 g)	Ash (g/100 g)	Total phenolic content (mg/kg)
Conte Marzotto control	68.40	9.93	1.70	0.42	257
Conte Marzotto break system	69.00	9.63	1.30	0.42	237
Conte Marzotto sizing and reduction system	68.00	10.25	2.20	0.43	269
Nogal control	71.00	10.33	0.80	0.42	222
Nogal break system	73.00	10.54	0.60	0.37	220
Nogal sizing and reduction system	69.00	10.03	1.70	0.49	231

Regarding dough development time (DDT), the results of the Wilcoxon-Mann Whitney rank-sum test do not show any statistically-significant difference between tested samples in both cultivars. Here, in the case of *Conte Marzotto*, DDT values were slightly higher for SR flour compared to both C and B flours (Table 3). Like WA, this increase in DDT might be related to its higher protein and total dietary fibre content (Table 2). Studies by Mis', Grundas, Dziki, and Laskowski (2012) and Gómez et al. (2011) support our findings, as they highlight increased DDT with increased total dietary fibre content, due to fibre-gluten interactions that delay gluten hydration and development. Moreover, as reported in Table 3, the higher strength of the gluten network in the case of the modern cultivar *Nogal*, led to higher DDT values and delayed gluten development compared to *Conte Marzotto* (Cappelli, Canessa, & Cini, 2020; De Santis et al., 2017).

Concerning dough stability (S), beginning with *Conte Marzotto*, the results of the Wilcoxon-Mann Whitney rank-sum test highlighted statistically-significant differences between B and C flours (p 0.046). Table 3 shows that S is higher for B flour compared to the control. At the same time, no statistically-significant difference was found between B and SR flours. For the *Nogal* cultivar, Table 3 shows the same increasing trend in the case of B flour. Here, S was 20.29% and 19.00% higher compared to C and SR flours, respectively. This increase in S is related to the composition of break system flours (Table 2). In particular, its higher starch (Gao et al., 2020; Sarker et al., 2008) and lower total dietary fibre content (Gómez et al., 2011), improves gluten development and dough rheological properties, resulting in an increased S. Specifically, the higher S in the case of *Conte Marzotto* B flour might be due to the synergistic effect of higher starch content (Gao et al., 2020) and lower dietary fibre content (Gómez et al., 2011), which guarantee an optimal gluten development.

With regard to the degree of softening (DS), the Wilcoxon-Mann Whitney rank-sum test did not find any statistically-significant differences between tested samples. Nonetheless, both for *Conte Marzotto* and *Nogal*, DS was lower for B flours compared to both C and SR flours (this is consistent with the higher values of S shown in Table 3). In the case of *Conte Marzotto* B flour, DS decreased by 12.12% and 6.45% compared to C and SR flours, respectively. These figures can be compared to decreases of 14.80% and 8.00% for *Nogal*. The same results are observed for the twenty minute drop (TMD) (Table 3). Specifically, in the case of *Conte Marzotto* B flour, TMD fell by 11.11% and 4.76% compared to C and SR flours, respectively. In the case of *Nogal* B flour, TMD fell by 12.50% compared to the control. The reasons for the reduction in DS and TMD for break system flours are the same as those that drive the increase in S. Higher starch (Gao et al., 2020; Sarker et al., 2008) and lower total dietary fibre content (Gómez et al., 2011) ensure correct gluten development and a dough with higher S, which, in turn, will have lower dough weakening indexes (e.g. DS and TMD).

3.3.2. *Chopin alveograph*

The results of alveograph tests are reported in Table 4. Regarding dough tenacity (P), the results of the Wilcoxon-Mann Whitney rank-sum test do not show any statistically-significant differences between tested samples in both cultivars. Nevertheless, in the case of *Conte Marzotto*, P values of B flour were 7.87% and 11.58% lower compared to C and SR flours, respectively. As reported in earlier work (Cappelli, Oliva, et al., 2020), P is closely related to the protein and gluten content of flour and, here, the reduction in P is due to lower protein and gluten content of break system flours, which result in doughs with lower viscosity and

Table 3

Results of farinograph tests expressed as mean of three replicates ± SD.

Flour sample	Water absorption (%)	Dough development time (min.)	Dough stability (min.)	Degree of softening (B.U.)	Twenty minute drop (B.U.)
Conte Marzotto control	49.60 ± 0.10	2.67 ± 0.14	4.25 ± 0.43	110.00 ± 10.00	150.00 ± 0.00
Conte Marzotto break system	47.93 ± 0.21	2.58 ± 0.14	5.00 ± 0.25	96.67 ± 15.28	133.33 ± 28.87
Conte Marzotto sizing and reduction system	49.77 ± 0.31	2.75 ± 0.25	4.33 ± 0.52	103.33 ± 5.77	140.00 ± 10.00
Nogal control	51.77 ± 0.25	2.83 ± 0.14	5.58 ± 0.38	90.00 ± 10.00	106.67 ± 11.55
Nogal break system	51.60 ± 0.53	2.83 ± 0.14	7.00 ± 1.32	76.67 ± 11.55	93.33 ± 23.09
Nogal sizing and reduction system	51.47 ± 0.25	2.83 ± 0.14	5.67 ± 0.38	83.33 ± 5.77	93.33 ± 11.55

Table 4

Results of alveograph tests (mean of five measurements (diskettes) for each proof). Results are expressed as the mean of the three replicates ± SD.

Flour sample	P (Dough tenacity)	L (Dough extensibility)	G (Index of swelling)	W (Deformation energy)	P/L (Curve configuration ratio)
Conte Marzotto control	36.47 ± 1.21	57.80 ± 6.72	16.88 ± 1.00	69.73 ± 4.99	0.65 ± 0.10
Conte Marzotto break system	33.60 ± 1.64	64.00 ± 18.32	17.37 ± 2.58	69.80 ± 10.93	0.56 ± 0.14
Conte Marzotto sizing and reduction system	38.00 ± 2.43	54.60 ± 4.01	16.45 ± 0.62	68.80 ± 2.99	0.71 ± 0.10
Nogal control	63.53 ± 2.34	49.47 ± 2.58	15.65 ± 0.41	133.27 ± 7.16	1.23 ± 0.01
Nogal break system	65.27 ± 1.70	50.67 ± 3.06	15.65 ± 0.48	140.80 ± 7.35	1.20 ± 0.05
Nogal sizing and reduction system	62.20 ± 3.03	54.80 ± 3.42	16.87 ± 0.93	134.87 ± 8.31	1.21 ± 0.10

tenacity (Cappelli et al., 2018, 2020c; Indrani, Manohar, Rajiv, Rao, & Venkateswara, 2007). Moreover, modern wheat varieties are characterized by higher protein (and gluten) content and by stronger gluten network (Cappelli, Canessa, & Cini, 2020; De Santis et al., 2017). As a result, the P values of *Nogal* flours (B, C, and SR) are almost double of the *Conte Marzotto* flours (Table 4).

With respect to G and L, the results of the Wilcoxon-Mann Whitney rank-sum test do not show any statistically-significant differences between tested samples in both cultivars. Concerning G, as reported in Table 4, the results remained substantially stable. With regard to *Conte Marzotto* B flour, L increased by 9.69% and 14.69% compared to C and SR flours, respectively. As reported by Gómez et al. (2011), L is inversely proportional to total dietary fibre content. Moreover, according to earlier work (Cappelli et al., 2018), if starch increases, L increases. Table 2 shows that *Conte Marzotto* B flour had higher starch and lower total dietary fibre content, which explains the higher L values reported in Table 4. In the case of *Nogal*, L values were highest for SR flour. The latter finding might be related to differences between modern and ancient wheat characteristics and, more importantly, to a more intense milling process which produces flour with lower particle size distribution and higher L (Lapčíková, Burešová, Lapčík, Dabash, & Valenta, 2019).

Concerning W, the results of the Wilcoxon-Mann Whitney rank-sum test do not show any statistically-significant differences between tested samples in both cultivars. Nonetheless, for *Nogal* B flour, W increased by 5.25% and 4.21% compared to C and SR flours, respectively (Table 4). As reported in earlier work (Cappelli, Oliva, et al., 2020), there is a statistically-significant relationship between W and protein content ($p < 0.001$). This correlation clearly explains the higher value of W obtained for break system flours, which had the highest protein content (Table 2 and Dexter, Preston, Martin, & Gander, 1994). Moreover, W is strictly related to the gluten quantity and quality. As a result, W is considered as one of the most important alveograph parameters (with the P/L) by millers and bakers. As widely reported in the literature, modern wheat varieties are characterized by higher protein (and gluten) content and by stronger gluten network (Cappelli, Canessa, & Cini, 2020; De Santis et al., 2017). In particular, the lower gliadins/glutenins ratio (i.e. higher glutenin content) and the improved glutenin allelic composition, had led to the success of modern wheat in bakery industry (Cappelli, Canessa, & Cini, 2020; De Santis et al., 2017). The results reported in Table 4 support these considerations, showing significantly higher W values (about double) compared to the ancient wheat *Conte Marzotto*.

Finally, with respect to the P/L ratio, the Wilcoxon-Mann Whitney rank-sum test did not highlight any statistically-significant differences between tested samples in both cultivars. The results obtained for *Nogal* (Table 4) are very similar for the three tested flours. In the case of *Conte Marzotto*, it is important to highlight that the P/L value obtained for B flour is slightly lower compared to C and SR flours (Table 4) – in particular, it is very close to the optimal value of 0.60. This is mainly due to the decrease in tenacity (P) and to the increase of extensibility (L) in the case of doughs made with *Conte Marzotto* B flour, which lead to the decrease of P/L value.

3.4. *Bread characteristics*

Table 5 summarises the results of the bread characterisation. Fig. 4a illustrates the bread loaves and slices (Fig. 4b) that were tested.

3.4.1. *Specific volume*

The results of the Wilcoxon-Mann Whitney rank-sum test highlighted a significantly higher bread specific volume for B flour in the case of *Nogal* (Table 5). In particular, the specific volume obtained using B flour

Table 5

Results of bread characterisation expressed as the mean of the three replicates ± SD.

Flour sample	Specific volume (L/kg)	Crumb density (g/ml)	Loaf height (mm)	Crumb moisture (g/100 g)	Crust moisture (g/100 g)
Conte Marzotto control	3.14 ± 0.08	0.277 ± 0.03	82.47 ± 0.38	42.40 ± 0.15	25.00 ± 0.35
Conte Marzotto break system	3.19 ± 0.10	0.273 ± 0.01	90.73 ± 3.59	42.24 ± 0.13	24.41 ± 0.16
Conte Marzotto sizing and reduction systems	3.13 ± 0.10	0.260 ± 0.03	81.00 ± 0.70	42.12 ± 0.05	24.74 ± 0.13
Nogal control	2.81 ± 0.02	0.328 ± 0.03	84.00 ± 1.82	42.77 ± 0.13	25.76 ± 0.06
Nogal break system	2.97 ± 0.14	0.323 ± 0.04	88.47 ± 5.25	42.65 ± 0.08	25.22 ± 0.10
Nogal sizing and reduction systems	2.79 ± 0.09	0.303 ± 0.04	82.63 ± 3.01	42.47 ± 0.10	25.45 ± 0.08

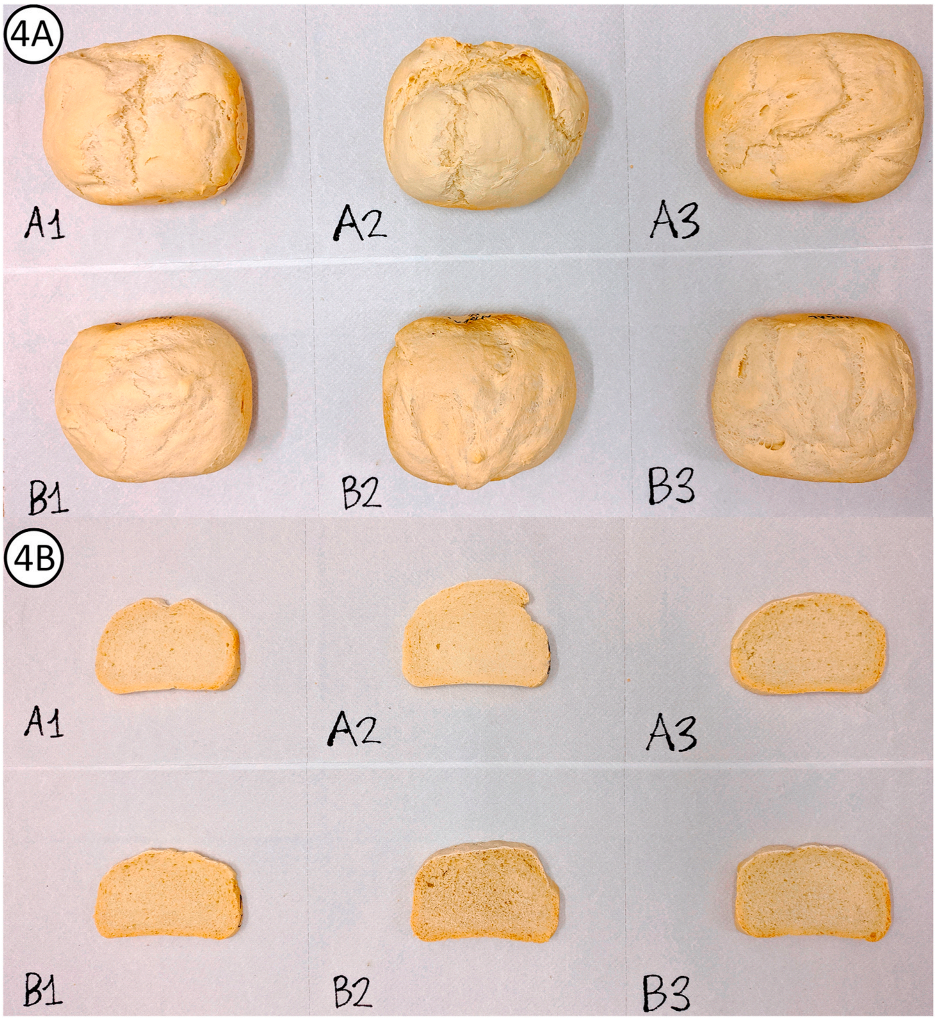

Fig. 4. Bread loaves (Fig. 4a) and slices of bread (Fig. 4b) obtained with the tested flours. A) *Conte Marzotto*. B) *Nogal*.

is significantly higher compared to the specific volume obtained using C flour (*p* 0.043) and SR flour (*p* 0.046). Although the difference was not significant for *Conte Marzotto*, the bread specific volume obtained using B flour was higher compared to C and SR flours (Table 5). The increase in bread specific volume in the case of break system flours is related to the lower total dietary fibre content (Table 2). As widely reported in the literature, flours characterized by lower total dietary fibre content are more suitable for breadmaking, and bread volume is higher due to lower gluten dilution and fewer gluten-fibre interactions (Fendri et al., 2016; Gómez et al., 2011). Moreover, in the case of the modern wheat *Nogal*, the positive effect on bread specific volume related to a lower total dietary fibre content is even more evident, since that the correct development of the stronger gluten network in modern wheats occur, better, with a lower content of disruptors (Fendri et al., 2016; Cappelli, Canessa, & Cini, 2020; De Santis et al., 2017; Gómez et al., 2011).

3.4.2. *Loaf height*

Regarding loaf height, the results of the Wilcoxon-Mann Whitney rank-sum test do not show any statistically-significant differences between tested samples in both cultivars. Nevertheless, the results obtained for specific volume (Table 5) were confirmed. In particular, for *Conte Marzotto* B flour, loaf height was 9.10% and 10.72% higher compared to C and SR flours (Table 5). Similarly, in the case of *Nogal* B flour, loaf height was 5.05% and 6.60% higher compared to C and SR flours (Table 5). As reported in section 3.4.1, the higher loaf height obtained for break system flours in both the tested cultivars is due to a lower total dietary fibre content, which supports the correct development of the gluten network (with subsequent higher gas holding capacity), due to lower gluten dilution and fewer gluten-fibre interactions (Fendri et al., 2016; Gómez et al., 2011).

3.4.3. *Crumb density*

With respect to crumb density, the results of the Wilcoxon-Mann Whitney rank-sum test do not show any statistically-significant differences between tested samples in both cultivars. In particular, values were very similar for all samples (Table 5). These results highlight that the milling system has little impact on this parameter which seems to be influenced by others factors like nitrogen fertilization of wheat, protein content of flour, and the correct management of water, bran, and middlings in breadmaking (Guerrini et al., 2020; Trappey, Khouryieh, Aramouni, & Herald, 2015).

3.4.4. *Crumb and crust moisture*

Concerning crumb and crust moisture, the results of the Wilcoxon-Mann Whitney rank-sum test do not show any statistically-significant differences between tested samples in both cultivars. Differences were minimal, as highlighted in Table 5. As expected, it seems that crumb and crust moisture are more influenced by pre-milling operations, such as wheat conditioning (Cappelli, Guerrini, et al., 2020), and post-milling stages related to breadmaking, such as the amount of water and other ingredients (Parenti et al., 2020).

4. Conclusions

Our results highlight that different roller mill systems significantly influence the composition of flours, dough rheological properties, and bread characteristics. The machine–product interaction can have a remarkable effect. In particular, break system flours have lower total dietary fibre content and higher starch content. On the other hand, flours recovered by the sizing and reduction system are characterized by higher total dietary fibre and phenolic content, and lower starch content. Regarding dough rheological properties, dough stability was higher for break system flours compared to the control. Moreover, in the case of *Nogal*, specific volume was significantly higher for break system flour compared to C and SR flours.

These findings clearly show that each part of the roller mill system produces different flours. Millers can use this result in production, as an alternative to simply collecting flour at the end of the milling process, as in current practice. In particular, flours obtained by the break system have better rheological performance and bread characteristics. On the other hand, flours recovered from the sizing and reduction system have a more interesting nutritional profile, due to their higher total dietary fibre and phenolic content. In conclusion, this strategy makes it possible, starting from the same batch of wheat, to use the milling process to modulate the characteristics of the obtained flours. These two flours could be sold to different markets: for example, consumers may be more interested in sizing and reduction system flours, with improved nutritional content, while bakers could be more interested in break system flours, given its better technological performance. Finally, the application of the proposed strategy has several additional advantages; these include ease of application, no additional expenditure, no lengthening of milling time, increased profits, better product differentiation, and the expansion of the potential clientele.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

CRediT authorship contribution statement

Alessio Cappelli: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing - original draft, Writing - review & editing. **Marco Mugnaini:** Formal analysis, Investigation, Writing - original draft. **Enrico Cini:** Conceptualization, Methodology, Validation, Supervision.

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.

Acknowledgements

The authors would like to thank Molino Cicogni for providing technical support in the milling process, and the raw materials.

References

AACC. (2000). *Approved methods of the American association of cereal chemists* (10th ed.) St. Paul, MN.

AOAC International. (2005). *Official methods of analysis, seventeenth ed. AOAC International.* Gaithersburg: Md.

Cappelli, A., Canessa, J., & Cini, E. (2020). Effects of CO2 snow addition during kneading on thermoregulation, dough rheological properties, and bread characteristics: A focus on ancient and modern wheat cultivars. *International Journal of Refrigeration, 117*, 52–60.

Cappelli, A., Cini, E., Guerrini, L., Masella, P., Angeloni, G., & Parenti, A. (2018). Predictive models of the rheological properties and optimal water content in doughs: An application to ancient grain flours with different degrees of refining. *Journal of Cereal Science, 83*, 229–235.

Cappelli, A., Cini, E., Lorini, C., Oliva, N., & Bonaccorsi, G. (2020). Insects as food: A review on risks assessments of tenebrionidae and gryllidae in relation to a first machines and plants development. *Food Control, 108*, 106877.

Cappelli, A., Guerrini, L., Cini, E., & Parenti, A. (2019). Improving whole wheat dough tenacity and extensibility: A new kneading process. *Journal of Cereal Science, 90*, 102852.

Cappelli, A., Guerrini, L., Parenti, A., Palladino, G., & Cini, E. (2020). Effects of wheat tempering and stone rotational speed on particle size, dough rheology and bread characteristics for a stone-milled weak flour. *Journal of Cereal Science, 91*, 102879.

Cappelli, A., Oliva, N., Bonaccorsi, G., Lorini, C., & Cini, E. (2020). Assessment of the rheological properties and bread characteristics obtained by innovative protein sources (Cicer arietinum, Acheta domesticus, Tenebrio molitor): Novel food or potential improvers for wheat flour? *LWT – Food Science and Technology, 118*, 108867.

Cappelli, A., Oliva, N., & Cini, E. (2020). Stone milling versus roller milling: A systematic review of the effects on wheat flour quality, dough rheology, and bread characteristics. *Trends in Food Science & Technology, 97*, 147–155.

Cappelli, A., Parretti, C., Cini, E., & Citti, P. (2019). Development of a new washing machine in olive oil extraction plant: A first application of usability-based approach. *Journal of Agricultural Engineering, 50*(3), 134–142.

De Santis, M. A., Giuliani, M. M., Giuzio, L., De Vita, P., Lovegrove, A., Shewry, P. R., et al. (2017). Differences in gluten protein composition between old and modern durum wheat genotypes in relation to 20th century breeding in Italy. *European Journal of Agronomy, 87*, 19–29.

Dexter, J. E., Preston, K. R., Martin, D. G., & Gander, E. J. (1994). The effects of protein content and starch damage on the physical dough properties and bread-making quality of Canadian durum wheat. *Journal of Cereal Science, 20*, 139–151.

Doblado-Maldonado, A. F., Pike, O. A., Sweley, J. C., & Rose, D. J. (2012). Key issues and challenges in whole wheat flour milling and storage. *Journal of Cereal Science, 56*(2), 119–126.

Fendri, L. B., Chaari, F., Maaloul, M., Kallel, F., Abdelkafi, L., Chaabouni, S. E., et al. (2016). Wheat bread enrichment by pea and broad bean pods fibers: Effect on dough rheology and bread quality. *LWT – Food Science and Technology, 73*, 584–591.

Finney, K. F., Yamazaki, W. T., Youngs, V. L., & Rubenthaler, G. L. (1987). Quality of hard, soft, and durum wheats. *Wheat and wheat improvement, 13*, 677–748.

Fusi, A., Guidetti, R., & Azapagic, A. (2016). Evaluation of environmental impacts in the catering sector: The case of pasta. *Journal of Cleaner Production, 132*, 146–160.

Gao, X., Tong, J., Guo, L., Yu, L., Li, S., Yang, B., & Zhai, S. (2020). Influence of gluten and starch granules interactions on dough mixing properties in wheat (Triticum aestivum L.). *Food Hydrocolloids*, 105885.

Gómez, M., Jiménez, S., Ruiz, E., & Oliete, B. (2011). Effect of extruded wheat bran on dough rheology and bread quality. *LWT – Food Science and Technology, 44*, 2231–2237.

Guerrini, L., Napoli, M., Mancini, M., Masella, P., Cappelli, A., Parenti, A., et al. (2020). Wheat grain composition, dough rheology and bread quality as affected by nitrogen and sulfur fertilization and seeding density. *Agronomy, 10*(2), 233.

Indrani, D., Manohar, R. S., Rajiv, J., & Rao, G. V. (2007). Alveograph as a tool to assess the quality characteristics of wheat flour for parotta making. *Journal of Food Engineering, 78*, 1202–1206.

International Association for Cereal Chemistry. (1992). *ICC-standard No 115/1. Approved 1972, revised*.

ISO. (2008). *ISO 27971. Cereals and cereal products-common wheat (Triticum aestivum L.)-Determination of alveograph properties of dough at constant hydration from commercial or test flours and testing milling methodology*. Geneva: Switzerland: International Organization for Standardization.

Kihlberg, I., Johansson, L., Kohler, A., & Risvik, E. (2004). Sensory qualities of whole wheat pan bread—influence of farming system, milling and baking technique. *Journal of Cereal Science, 39*(1), 67–84.

Kucek, L. K., Dyck, E., Russel, J., Clark, L., Hamelman, J., Burns-Leader, S., et al. (2017). Evaluation of wheat and emmer varieties for artisanal baking, pasta making, and sensory quality. *Journal of Cereal Science, 74*, 19–27.

Kweon, M., Slade, L., Levine, H., & Gannon, D. (2014). Cookie-versus cracker-baking—what's the difference? Flour functionality requirements explored by src and alveography. *Critical Reviews in Food Science and Nutrition, 54*(1), 115–138.

Lapčíková, B., Burešová, I., Lapčík, L., Dabash, V., & Valenta, T. (2019). Impact of particle size on wheat dough and bread characteristics. *Food Chemistry, 297*, 124938.

Ma, W., Sutherland, M. W., Kammholz, S., Banks, P., Brennan, P., Bovill, W., et al. (2007). Wheat flour protein content and water absorption analysis in a doubled haploid population. *Journal of Cereal Science, 45*, 302–308.

Migliorini, P., Spagnolo, S., Torri, L., Arnoulet, M., Lazzerini, G., & Ceccarelli, S. (2016). Agronomic and quality characteristics of old, modern and mixture wheat varieties and landraces for organic bread chain in diverse environments of northern Italy. *European Journal of Agronomy, 79*, 131–141.

Miś, A., Grundas, S., Dziki, D., & Laskowski, J. (2012). Use of farinograph measurements for predicting extensograph traits of bread dough enriched with carob fibre and oat wholemeal. *Journal of Food Engineering, 108*, 1–12.

Pagani, M. A., Marti, A., & Bottega, G. (2014). Wheat milling and flour quality evaluation. *Bakery products science and technology*, 17–53.

Parenti, O., Guerrini, L., Cavallini, B., Baldi, F., & Zanoni, B. (2020). Breadmaking with an old wholewheat flour: Optimization of ingredients to improve bread quality. *LWT – Food Science and Technology, 121*, 108980.

Posner, E. S. (2003). Principles of milling. In B. Caballero, L. C. Trugo, & P. M. Finglas (Eds.), *Encyclopedia of food science and nutrition* (2nd ed., pp. 3980–3986). London: Academic Press.

Recchia, L., Cappelli, A., Cini, E., Garbati Pegna, F., & Boncinelli, P. (2019). Environmental sustainability of pasta production chains: An integrated approach for comparing local and global chains. *Resources, 8*(1), 56.

Roncolini, A., Milanović, V., Aquilanti, L., Cardinali, F., Garofalo, C., Sabbatini, R., & Foligni, R. (2020). Lesser mealworm (Alphitobius diaperinus) powder as a novel baking ingredient for manufacturing high-protein, mineral-dense snacks. *Food Research International, 131*, 109031.

Rosentrater, K. A., & Evers, A. D. (2017). Kent's technology of cereals: An introduction for students of food science and agriculture. *Woodhead Publishing*.

Sarker, I. M., Yamauchi, H., Kim, S., Matsuura-Endo, C., Takigawa, S., Hashimoto, N., et al. (2008). A farinograph study on dough characteristics of mixtures of wheat flour and potato starches from different cultivars. *Food Science and Technology Research, 14*, 211–216.

Trappey, E. F., Khouryieh, H., Aramouni, F., & Herald, T. (2015). Effect of sorghum flour composition and particle size on quality properties of gluten-free bread. *Food Science and Technology International, 21*(3), 188–202.