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Impact of heat treatments on technological performance of re-milled semolina dough and bread

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ABSTRACT

Re-milled semolina used for bread making is appreciated from consumers for its typical sensory features and nutritional attributes. Fluid bed drying treatment can be applied to semolina to change its bacteriological properties, to prolong shelf life by decreasing the risk of mould development, and to degrade some mycotoxins. The main goal of the present work was to evaluate the impact of heat treatment on structural development of semolina dough during mixing and leavening and on bread characteristics. Semolina was treated with fluidized bed drying at 90 °C, 120 °C, or 150 °C for 5, 15 or 30 min. The heat treatment affected colour, moisture content, and farinograph indices of semolina. Results showed that the use of heat treated re-milled semolina significantly ($P < 0.05$) affected the dough leavening kinetics and bread parameters such as crumb structure and mechanical parameters, in particular for treatment at 150 °C for 30 min. On the contrary, after treatment of semolina at 120 °C for 30 min, an improvement in the leavening phase of dough and no significant effects on bread quality were observed. Therefore, moderate heat treatment can be applied to semolina without having any negative impact.

1. Introduction

Traditionally, Triticum turgidum, subsp. durum is adopted for production of semolina, the preferred raw material for pasta making, due to its high protein content and the appropriate dough structure properties. In southern Italy, durum wheat is also used for bread making (Pasqualone, 2012). In fact, in 2003 (Raffo et al., 2003) and in 2009 (Commission Regulation (EC) No 516/2009), two Italian durum wheat breads commonly produced in Apulia (Altamura bread) and in Sicily in the Dittaino area (Dittaino bread) respectively, were recognized as a Protected Denomination of Origin (PDO) product, a designation that recognizes foodstuffs originating and totally produced in a specific geographical area. In particular, the re-milled semolina in Altamura bread is at least 80 g/100g of the raw material from one or a combination of Appulo, Arcangelo, Simeto and Duilio durum wheat cultivars from Altamura in Apulia, Southern Italy (Raffo et al., 2003).

Altamura bread is appreciated by consumers for its typical sensory features and nutritional attributes due to the presence of higher protein content (Raffo et al., 2003) and carotenoid pigments with provitamin A activity (Pasqualone, 2017). The sensory features include a thick brown crust with a typical toasted odor, coupled to a yellow and dense structure of crumb showing a high firmness and a coarse grain, accompanied by a marked sour taste and odor. In addition, Altamura bread has a long shelf life, dueto the higher water binding capacity of durum wheat flour, and a low loaf volume.

Dough viscoelastic and gas-retention properties during leavening and cooking have substantial effects on the texture of baked products. The characteristic air bubble structure of bread depends on both proteins and the state of flour starch (Shibata et al., 2011). Previous reports in the scientific literature indicate that heat treatments on wheat flour can improve cake and bread quality, since they result in a slower retrogradation of amylopectin,a finer texture, moister crumb and sweeter taste (Neill, Al-Muhtaseb, & Magee, 2012; Purhagen, Sjöö, & Eliasson, 2011). Interestingly, denaturation of the proteins and enzymes in the heat treated flour increases batter expansion, preventing collapse during baking and conferring higher volume and stability to the product (Sahin et al., 2008).

Dry heating of wheat flour at 120 °C for 30 min increased batter viscosity and stability, due to the formation of a stronger gel network (Meza et al., 2011) and increased the volume of Kasutera cake (Nakamura, Koshikawa, & Seguchi, 2008). As reported by Neill et al. (2012) the degree of protein denaturation in the flour due to heat

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treatment represents an important parameter in the bakery products quality. In fact, a positive effect on baking quality was found after treatment in a fluid bed dryer, again as a consequence of increased dough viscosity, linked to denatured protein and partial gelatinization of starch granules. Therefore, pre-treatment under specific physico - chemical conditions could produce technological variations that may be useful and are interesting to investigate. Fluid bed drying of semolina can be applied to improve bacteriological properties by reducing moisture content, to prolong shelf life or to decrease the risk of mould development, and to degrade some mycotoxins (Vidal, Sanchis, Ramos, & Marín, 2015). Heat treatments also had a high impact on dough properties as revealed from some farinograph indices, which were well correlated with parameters obtained from calorimetric analysis and modifications in microstructure observed by Scanning Electron Microscope (SEM) (Shanakhat et al., 2019).

Although several studies were published about the effect of heat treatments on flour and semolina, no information concerning the effect of these processing techniques in RM-semolina and its technological properties during bread making are available.

This study aims to investigate the technological performance of RM-semolina from Altamura after fluid bed drying at different time and temperature settings. The effects of heat treatment on dough development during mixing and leavening and on bread characteristics were examined, with the intent to provide the information for the potential use of heat - treated RM-semolina as an ingredient for bakery products.

2. Materials and methods

2.1. 1Materials

Re-milled durum wheat (RM - semolina: 14.4 g/100 g proteins) was purchased from a company in Altamura (Bari, Italy) and stored in plastic containers at 15–20 °C until analysis.

The wet gluten content and dried gluten content were 39.6 g/100 g and 14.9 g/100 g respectively.

2.2. Thermal treatments

RM - semolina thermal treatments was carried out in a discontinuous fluidized bed dryer (Sherwood Scientific Model MK11, UK), at different temperatures, 90 °C (A), 120 °C (B), 150 °C (C); and for different time, 5, 15, 30 min. The air relative humidity was 2.5%–0.35% (g/100 g). The air flow speed was constant and set at level 4. 300 g of RM - semolina were treated for each batch. Temperature and air velocity were monitored using a digital thermometer (range -50 -300 °C ± 1 °C) and a hot wire anemometer (range 0.4–30 m/s ± 3%), respectively.

2.3. Colour

Colorimetric indices (L*, a*, b*) of RM-semolina samples were measured with a tristimulus colorimeter (Minolta Chroma Meter model CR 300, Milan, Italy) with a circular measurement area (D = 8 mm) according to Romano et al. (2016). Results were the average of three determinations.

2.4. Moisture content

The moisture content of RM-semolina, dough and bread (crust and crumb) was determined in triplicate for each sample by the AACC method (number 44–15.02, 1999). The results were calculated as percentage (%) of water per sample weight (g/100g).

2.5. Farinograph analysis of treated RM-semolina

Farinograph curves of both control and treated samples were acquired using a Brabender farinograph (Type AT, Brabender OHG, Duisburg, Germany), fitted with 50 g mixing bowl, according to AACC (1999) methods. Water absorption (WA), dough development time (DDT), dough stability (DS), degree of softening (DOS) and elasticity (E) were determined and the results were expressed as the average value of three replicates for each sample.

2.6. Bread dough leavening analysis

Bread doughs with both heat treated and untreated RM-semolina were prepared using a Brabender farinograph (Type AT, Brabender OHG, Duisburg, Germany), fitted with 50 g mixing bowl. Doughs were prepared according to the following recipe: RM-semolina, 50 g; water, 36 g; salt, 0.65 g; brewing yeast, 0.37 g. Moisture content of treated RM-semolina was adjusted to the same moisture content of control, equal to 47 g/100 g. For each blend, the farinographic development time was considered as the mixing time. The maximum consistency of all doughs was measured.

Just after mixing, 62 g of dough was placed on a flat surface where it could expand in every direction without constraint during the leavening stage. The dough was incubated at 36 ± 1 °C, 70% relative humidity (RH) for 170 min. The following parameters were continuously and automatically recorded: a) internal humidity and temperature by means of data logger (Logger Escort mod. 10D8, Gamma Instrument s.r.l., Naples, Italy); b) volume (V) expansion by means of a camera Olympus® C-7070Wide ZOOM camera (Olympus, Milan, Italy) mounted on a photographic bench. The V of dough was calculated by means of Image Analysis software (Image Pro Plus 6.1 for Windows®, Media Cybernetics Inc.) as reported by Romano, Cavella, Toraldo, and Masi (2013).

Each average value represents the mean of 3–7 independent measurements.

2.7. Impact of heat treatments on bread

2.7.1. Bread making procedure

Samples with the most different behavior and leavening performance compared with the control dough were selected for bread characterization.

In each case, 2500 g of dough were prepared according to the recipe reported above (see section 2.6). All doughs were prepared in a planetary kneader (Kitchen Aid, USA), using the farinographic development time as the mixing time. 800 g of dough were aliquoted into aluminum molds (25 × 15 cm) and incubated at 36 ± 1 °C, 70% RH for the optimal leavening time (Romano, Toraldo, Cavella, & Masi, 2007). Baking was carried out in a conventional electric oven (Moretti Forni S.p.A., Pesaro, Italy) at 180 °C for 110 min. Three lots were produced for each selected treatment and three bread loaves were obtained for each lot.

2.7.2. Loaf bubble structure

Samples were cut into 20 mm thick slices using an electric knife. Six samples were taken from the middle of the loaf. 2 dimensional loaf slice images were analyzed using an image analysis protocol as reported by Romano et al. (2013), with some minor modifications. All measurements were carried out using an Olympus® mod. C-7070Wide ZOOM camera (Olympus, Milan, Italy). Images were processed by means of Image Pro Plus 6.1 (Media Cybernetics Inc.). Structural computed parameters were the following:

- number of bubbles counted (n);
- area of the loaf section (Ad);
- bubble area (A_i);
- bubble wall roundness. Roundness is a shape factor and calculates circularity of an object. In this measure, a perfect circle has a shape factor of 1 and a line has a shape factor approaching zero.

Gas bubble area fractions (AF) were calculated using the following equation:

$$AF\,(\%) = \frac{\sum_i^n A_i}{Ad} \tag{1}$$

Each result is the average of three different bread production runs.

2.7.3. Mechanical analysis

Crumb samples of each loaf were submitted to a compression test by means of an Instron Universal Testing Machine (Instron Ltd., mod. 4467, High Wycombe, GB), equipped with a 1 kN load cell. Cylindrical samples (diameter 16 mm, height 16 mm) were placed between parallel plates and compressed to a final deformation of 80%, at a crosshead speed of 60 mm/min. For each loaf, five measurements were performed. True stress – Hencky strain relationships were derived from load-displacement curves and the mechanical behavior of the bread was described by means of a semi-empirical mathematical model (Masi, Sepe, & Cavella, 1997), and model parameters were estimated by Table Curve 2D software,(version 5.01, Systat software Inc., USA).

2.8. Statistical analysis

All the parameters were expressed as mean value ± standard deviation. Differences among control and treated samples were determined by using SPSS (Statistical Package for Social Sciences) Package 6, version 15.0 (SSPS Inc., Chicago, IL, USA). Significance was determined by Anova (Duncan's test) at a significance level of 0.05.

3. Results and discussion

3.1. Impact of heat treatments on re-milled semolina

Table 1 shows the colorimetric indices (L*, a*, b*) determined in control and treated RM-semolina samples. In food industries, the most common color measurement method is based on the color-space system L*, a*, b* as defined by the Commission Internationale de l'Eclairage (CIE). L* values, which quantify the lightness of the product, ranged from 94.3 ± 0.07, for semolina treated at 150 °C (C) for 30 min, to 95.1 ± 0.10 in the sample treated at 150 °C for 5 min. Despite the high temperature reached during the heat treatment, no burned particles were present. In Table 1 the red index (a*), which is strictly linked to the Maillard reaction (Cavazza et al., 2013; Pasqualone, Paradiso, Summo, Caponio, & Gomes, 2014), was within a range of 2.7–3.3 and progressively increased as the heat treatment time increased. Sample yellowness is summarized by the b* value, and control's b* was not significantly different ($P < 0.05$) respect to samples treated for shorter treatment durations. But b* values increased after treatments at 150 °C (C) for 15 min, and for all 30 min treatments. After only 5 min of heat treatment, the L* value of samples were significantly higher than control. L* values of RM -semolina (94.6) were significantly higher than mean level reported for semolina (88.9) by Shanakhat et al. (2019), this difference could be due to the higher lightness associated to the semolina re-milling, as well as the increase of a* value and the reduction of b* value.

The effect of treatment temperature (A, B and C) on moisture content of samples was evident. As expected, the initial level of moisture value (11.8 g/100 g) in semolina (control) decreased after the thermal treatments (Table 1) and the samples treated at 120 °C (B) or 150 °C (C) for 30 min were completely dried (not detected), while A samples after 30 min showed a moisture content of 0.15% (g/100 g).

Table 1 shows data obtained from the Brabender farinograph, indicating a high impact of thermal treatment on the structure and properties of RM-semolina dough. In particular, water absorption (WA), which allows for quantifying the exact content of water necessary to obtain a specific value of dough consistency corresponding to 500

Table 1

RM – semolina properties and farinograph parameters. Each value is expressed as mean ± SD.

sample	L*	a*	b*	Moisture content (g/100g)	WA (g/100g)	DDT (min)	DS (min)	DOS (BU)	E (BU)
control	94.60 ± 0.46^{ab}	-3.03 ± 0.09^{b}	17.60 ± 0.15^{a}	11.83 ± 0.03^{h}	60.43 ± 0.15^{a}	1.25 ± 0.07^{a}	3.06 ± 0.46^{a}	63.67 ± 5.13^{f}	92.33 ± 4.04^{b}
A (90°C) 5min	95.03 ± 0.18^{c}	-2.73 ± 0.01^{c}	17.36 ± 0.20^{a}	5.98 ± 0.16^{g}	74.53 ± 1.63^{b}	1.46 ± 0.11^{ab}	6.32 ± 0.04^{a}	37.00 ± 13.53^{e}	85.00 ± 8.49^{b}
A (90°C) 15min	94.88 ± 0.05^{bc}	-2.77 ± 0.01^{c}	17.50 ± 0.04^{a}	2.46 ± 0.19^{e}	80.50 ± 0.30^{d}	1.54 ± 0.03^{ab}	17.31 ± 2.15^{cd}	15.00 ± 6.00^{cd}	70.00 ± 6.93^{a}
A (90°C) 30min	94.61 ± 0.01^{ab}	-3.31 ± 0.06^{a}	19.35 ± 0.05^{c}	0.15 ± 0.59^{a}	82.57 ± 0.15^{e}	2.32 ± 0.15^{b}	22.40 ± 1.00^{e}	6.33 ± 2.08^{abc}	65.67 ± 6.51^{a}
B (120°C) 5min	94.94 ± 0.07^{bc}	-2.77 ± 0.03^{c}	17.65 ± 0.13^{a}	3.60 ± 0.12^{f}	77.03 ± 0.12^{c}	1.83 ± 0.40^{ab}	13.97 ± 2.90^{bc}	19.00 ± 3.00^{d}	68.00 ± 3.61^{a}
B (120°C) 15min	94.84 ± 0.21^{bc}	-2.80 ± 0.03^{c}	17.36 ± 0.11^{a}	1.98 ± 0.14^{d}	83.03 ± 2.89^{e}	3.58 ± 1.43^{c}	11.93 ± 2.27^{b}	5.00 ± 4.24^{abc}	70.50 ± 9.19^{a}
B (120°C) 30min	94.59 ± 0.08^{ab}	-3.30 ± 0.01^{a}	19.40 ± 0.04^{c}	nd	87.13 ± 0.38^{f}	5.02 ± 0.59^{d}	18.51 ± 2.01^{d}	3.00 ± 2.65^{ab}	59.33 ± 0.58^{a}
C (150°C) 5min	95.05 ± 0.10^{c}	-2.83 ± 0.02^{c}	17.60 ± 0.13^{a}	1.28 ± 0.07^{c}	82.77 ± 0.67^{e}	1.80 ± 0.33^{ab}	14.51 ± 2.32^{bc}	12.67 ± 2.52^{bcd}	62.67 ± 8.02^{a}
C (150°C) 15min	94.61 ± 0.05^{ab}	-3.32 ± 0.10^{a}	19.61 ± 0.27^{c}	0.91 ± 0.05^{b}	85.50 ± 0.52^{f}	5.54 ± 0.55^{d}	14.73 ± 1.29^{bcd}	5.33 ± 2.31^{abc}	63.67 ± 6.51^{a}
C (150°C) 30min	94.33 ± 0.07^{ab}	-2.99 ± 0.70^{ab}	18.67 ± 0.35^{b}	nd	86.97 ± 0.32^{f}	9.28 ± 0.80^{e}	16.79 ± 2.80^{cd}	1.33 ± 1.53^{a}	59.33 ± 11.37^{a}

Different letters in the same column indicate significant differences ($P < 0.05$). WA: water absorption; DDT: dough development time; DS: dough stability; DOS: degree of softening; E: elasticity.
nd: not detected.

Brabender Units (BU), was equal to 60.4 ± 0.15 g/100g in the control. This is higher than the value reported by Shanakhat et al. (2019) in semolina (55.5 g/100g). This difference could be due to damage to starch granules as a consequence of milling, which has been reported to be linked to an increase in WA (Chiavaro, Vittadini, Musci, Bianchi, & Curti, 2008). The mean WA values of RM-semolina treated increased with the duration of heat treatment (5, 15 or 30 min) for each examined temperature: 90 °C (A), 120 °C (B) and 150 °C (C), respectively.

Dough development time (DDT) increased with the temperature and duration of the heat treatment; its mean value was equal to 1.3 min in the control, and increased in all doughs obtained from semolina treated at A, B and C from 5 to 30 min. The increase of DDT could be due to the lack or delay of gluten network formation associated with denaturation of proteins, confirming the results of other studies (Shanakhat et al., 2019; Van Steertegem, Pareyt, Brijs, & Delcour, 2013).

A similar trend was observed for dough stability (DS), which was significantly higher after prolonged heating time and increase of temperature compared to the control. In particular, the mean DS value of control was equal to 3.06 min and increased after 5–30 min of different treatments (A, B and C). On the contrary, DOS value which was equal to 63.7 BU in control, decreased after 5 and 30 min of A, B and C treatments.

Also the elasticity values showed significant differences ($P < 0.05$) among analyzed doughs, with the highest level in the control (92.3 ± 4.04 BU), decreasing from 7.93 to 28.87% after 5 and 30 min of A treatment, from 26.35% to 35.74% of B and, from 32.1% to 35.7% of C, respectively.

Overall, these data demonstrate that thermally treated RM -semolina required more time to develop into a dough, but this dough was more stable compared to the control. Furthermore, the increase of the WA value is related to the higher water uptake of starch granules, which are damaged from high temperature, especially when the treatment is prolonged. In addition, the observed changes are affected by the loss of the cross-linked protein network surrounding starch granules, since heat treatment leads to changes in starch-protein and starch-starch interactions. As a consequence, the total structure of the dough was impacted, as demonstrated by reduction in both DOS and elasticity in doughs. In fact, flour particles could be hydrated more slowly for the decreased amount of free SH groups after the heat treatment (Mann et al., 2014; Shanakhat et al., 2019). The significant differences of farinograph parameters after thermal treatment are due, in particular, to protein denaturation starting at a temperature range of 50–80 °C, with a consequent reduction of their solubility in water (Mann et al., 2014).

3.2. Impact of heat treatments on dough

In order to investigate the effect of heat treated RM-semolina on dough properties, the water activity and the consistency at the end of mixing of the dough were evaluated (Table 2). For water activity, we

Table 2
aw and consistency of RM – semolina doughs. Each value is expressed as mean ± SD.

Sample	aw	Consistency at the end of mixing
control	0.908 ± 0.016^{a}	244.66 ± 2.51^{a}
A5min	0.926 ± 0.007^{abc}	307.00 ± 18.33^{abc}
A15min	0.930 ± 0.008b^{cde}	328.40 ± 63.35^{bc}
A30min	0.936 ± 0.004b^{cde}	325.5 ± 31.81^{abc}
B5min	0.929 ± 0.006b^{cd}	264.00 ± 60.50^{ab}
B15min	0.949 ± 0.025^{e}	260.15 ± 25.31^{ab}
B30min	0.984 ± 0.004^{f}	429.5 ± 26.16^{de}
C5min	0.945 ± 0.029^{cde}	351.66 ± 19.62^{bcd}
C15min	0.952 ± 0.023^{e}	359.50 ± 13.43^{cd}
C30min	0.986 ± 0.004^{f}	465.66 ± 26.40^{e}

Different letters in the same column indicate significant differences ($P < 0.05$).

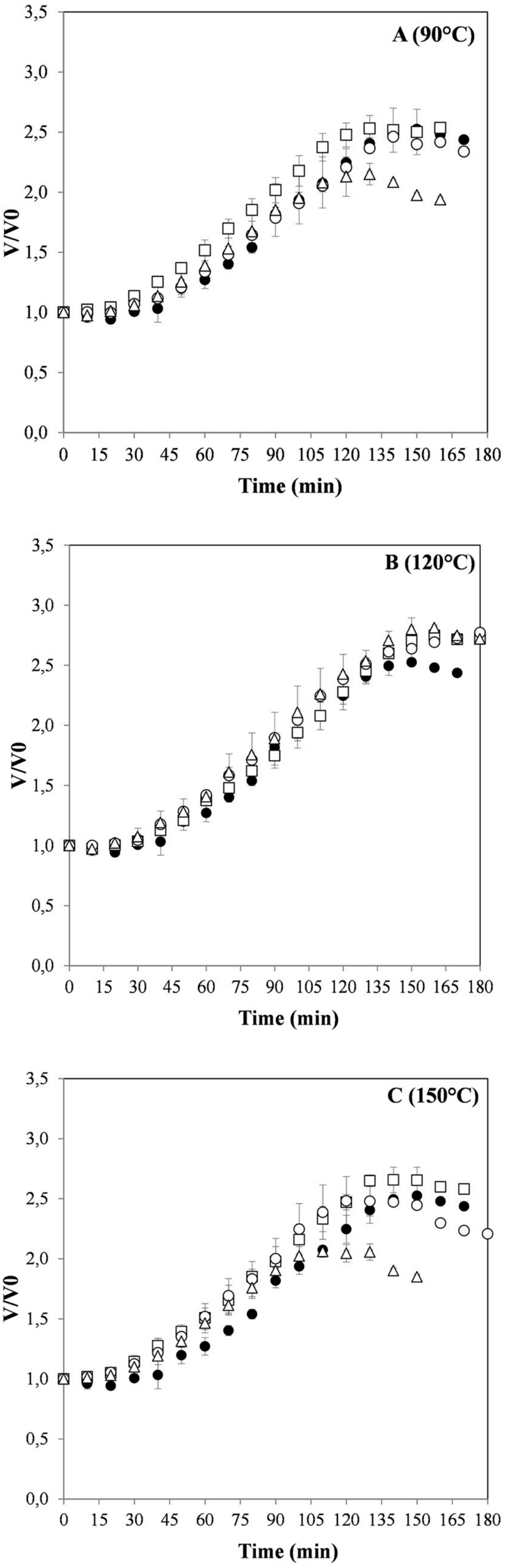

Fig. 1. Volume ratio vs. leavening time of control and treated (A, B, C) semolina doughs for different times: 0 min (●), 5 min (fx1), 15 min (○) and 30 min (Δ).

observed levels ranging from 0.908 ± 0.016, in the control, with a gradual increase with temperature and time of treatment up to 0.986 ± 0.002 in the C sample treated for 30 min, since a higher level of water was added in these doughs, affecting water activity.

The mean level of consistency at the end of mixing was equal to 244.66 ± 2.51 BU in the control, and a gradual increase was observed for each treatment as the heat treatment time was prolonged. After 30 min of heat treatment, the consistency ranged from 325.5 ± 31.81 BU at 90 °C to 465.7 ± 26.40 BU at 150 °C. This trend may be due to the denaturation of proteins with the consequent increase of consistency, confirming the results of farinographic indices DDT, DS, DOS and E (see § 3.1). In fact heat treatment of flour denatures most protein at temperatures from 50 °C to 80 °C with conformational changes and the formation of disulphide bond linked aggregates which have a significant impact on rheological properties e.g. a higher batter viscosity (Neill et al., 2012).

Leavening is the *critical* phase of bread making, during which the dough volume increases drastically (Romano et al., 2013). The volume expansion ratio of the dough was investigated by means of an Image Analysis protocol during leavening. Fig. 1 shows the volume expansion ratio over the leavening time of semolina dough obtained from control and thermally treated RM-semolina (A, B and C), evaluated in terms of volume expansion ratio (V/V0), where V is the volume at time t and V0 the volume at time 0. For all cases investigated, the trend of change in volume was the same. The typical curve of volume expansion ratio was characterized by a lag, a growth, a stationary and a decline phases as also reported by previous papers (Romano et al., 2007; 2013). The duration of phases and volume expansion ratio were depended on both time (5, 15, 30 min) and temperature (A, B, C) of heating treatment. In particular, a significant increase in dough volumes was observed from heat treated semolina as compared to the control. The volume expansion ratio of control dough increases from 1.0 to a maximum value of 2.5 (Fig. 1). However, as the treatment duration increases, the dough volume expansion decreases. In particular, A 5 min and B 30 min showed the best performance during leavening, while A and C loaves treated for 30 min showed the lowest volume ratio values. The effect of heat treatments evaluated on the bread doughs during the leavening phase can be explained by the formation of gluten aggregates in the flour treated for long durations (30 min), resulting in decreased protein solubility and lower network strength in dough, as reported by Mann, Schiedt, Baumann, Conde-Petit, and Vilgis (2014) that heat treatment can modify the interactions between gluten and the starch network of dough. Gluten is a complex molecule consisted of glutenin (polymeric), which plays a role in dough elasticity and strength (Khatkar, 2006), and gliadin (monomeric), which is responsible for dough extensibility and viscosity (Wieser, Bushuk, & MacRitchie, 2006, pp. 213–240). The volume expansion in dough depends on an appropriate balance of glutenin and gliadin (Khatkar, Bell, & Schofield, 1995). The insufficient gluten elasticity can result in a decreased dough volume, while increases in elastic gluten lead to higher dough volume (Hoseney, 1994, pp. 197–211). The effects of low volume expansion were more pronounced in the doughs obtained from the semolina treated at very high temperature (150 °C), while for treatments at lower temperatures there was actually an increase in volume expansion. These changes were marked by modifications in the gluten-starch network due to heat treatments.

3.3. 3Impact of heat treatments on bread

Bread samples were prepared considering the treated RM-semolina dough which had shown the best (A 5 min and B 30 min) and the worst (C 30 min) performance during leavening (Fig. 1). Between the best treatments, A 5 min and B 30 min, we have been selected B 30min for bread making experiments, since a more drastic treatment can exert an effect on shelf life and can decrease the risk of mould development and can degrade some mycotoxins (Shanakhat et al., 2019). A control bread sample was also considered. To prevent dough collapse during baking, the optimal leavening time was fixed (Correa, Pérez, & Ferrero, 2012; Romano et al., 2007) and was 70 min for C 30 min doughs and 100 min for control and B 30 min doughs.

Table 3

Parameters of breads made with untreated (control) and heat treated for 30 min RM-semolina at 120 °C and 150 °C. Each value is expressed as mean ± SD.

Parameter	control	B (120 °C)	C (150 °C)
moisture content of crumb (g/100g)	47.66 ± 0.82^b	47.63 ± 0.40^b	47.00 ± 0.32^a
aw of crumb	0.957 ± 0.01^a	0.957 ± 0.00^a	0.954 ± 0.01^a
moisture content of crust (g/100g)	22.82 ± 2.16^a	23.77 ± 2.67^a	23.02 ± 2.12^a
aw of crust	0.881 ± 0.187^a	0.864 ± 0.483^a	0.869 ± 0.188^a
area (mm^2)	0.23 ± 0.03^c	0.19 ± 0.003^b	0.15 ± 0.008^a
roudness	1.31 ± 0.01b	1.24 ± 0.03a	1.20 ± 0.09a
n/Ad	13.05 ± 0.64^b	14.06 ± 0.25^b	11.05 ± 0.51^a
AF (%)	29.2 ± 1.4^b	26.7 ± 0.3^b	17.7 ± 1.5^a
k_1 (kPa)	12.59 ± 3.78^a	11.77 ± 3.01^a	71.52 ± 22.37^b
k_1/k_2	0.076 ± 0.62^{ab}	0.006 ± 0.05^a	0.140 ± 0.84^b
ν	0.44 ± 0.009^a	0.45 ± 0.012^a	0.48 ± 0.020^b
a	0.206 ± 0.002^b	0.178 ± 0.15^a	0.173 ± 0.11^a

Different letters in the same row indicate significant differences ($P < 0.05$). Crumb structure parameters: n, number of bubbles counted; Ad, area loaf section; AF, gas bubble area fraction.

In Table 3, moisture content and water activity of both crust and crumb, bubble macrostructure parameters and the crumb firmness measurements of all bread loafs are reported.

The mean crumb moisture values were similar for all the samples (from 47.0 g/100 g in bread from treated sample at 150 °C for 30 min, to 47.7 g/100 g in the control), as well as the crust moisture (from 22.8 g/100 g in the control, to 23.8 g/100 g in bread from treated sample at 120 °C for 30 min). Also the water activity in both crumb and crust was not significantly different in bread from treated samples compared to the control. The moisture levels reported in baked wheat soft flour bread were 43.48 g/100 g in crumb and 18.16 g/100 g in crust (Gao, Wong, Lim, Henry, & Zhou, 2015). These differences are associated with the higher water binding capacity of durum wheat flour, which is known to be responsible for a slower firming rate and a prolonged shelf life of the bread (Chiavaro et al., 2008).

Fig. 2 shows characteristic images of central slices of breads made with untreated RM-semolina (control) and B and C samples for 30 min, respectively. The control and B breads had a crumb structure with large and uneven bubbles, while C showed smaller and denser bubbles.

From a macrostructural point of view, the crumb of bread is a solid foam characterized by a high porosity, also classified as a cellular solid (Keetels, Van Vliet, & Walstra, 1996). Bubble size distribution was highly correlated with the visual appeal of the bread and its texture. Image analysis was carried out to examine the effect of heat treatments on bubble macrostructure of bread crumb (Fig. 2). A statistically representative sample of bubbles can be identified from the digital images by using a quantitative image analysis procedure. Results of bread bubble size distribution by means of an image analysis protocol are illustrated in Table 3.

Significant differences ($P \leq 0.05$) were detected for area and roundness of samples (Table 3). Bread made with treated RM-semolina (B and C) showed a denser and more compact (smaller in size) structure compared to the control. In fact, bubbles in the control treatment showed the highest area and roundness, therefore the control bubbles were the least circular. From the n/Ad parameter, where n was the number of bubbles counted and Ad was the area loaf section, it was observed that the smallest number of bubbles was found in the C sample. This statistical datum provides additional evidence supporting the view that digital images can be useful in analysing bread structure. AF (gas bubble area fraction) in the control bread had a mean value of 29.2 ± 1.4%, showing a significant difference from the treated

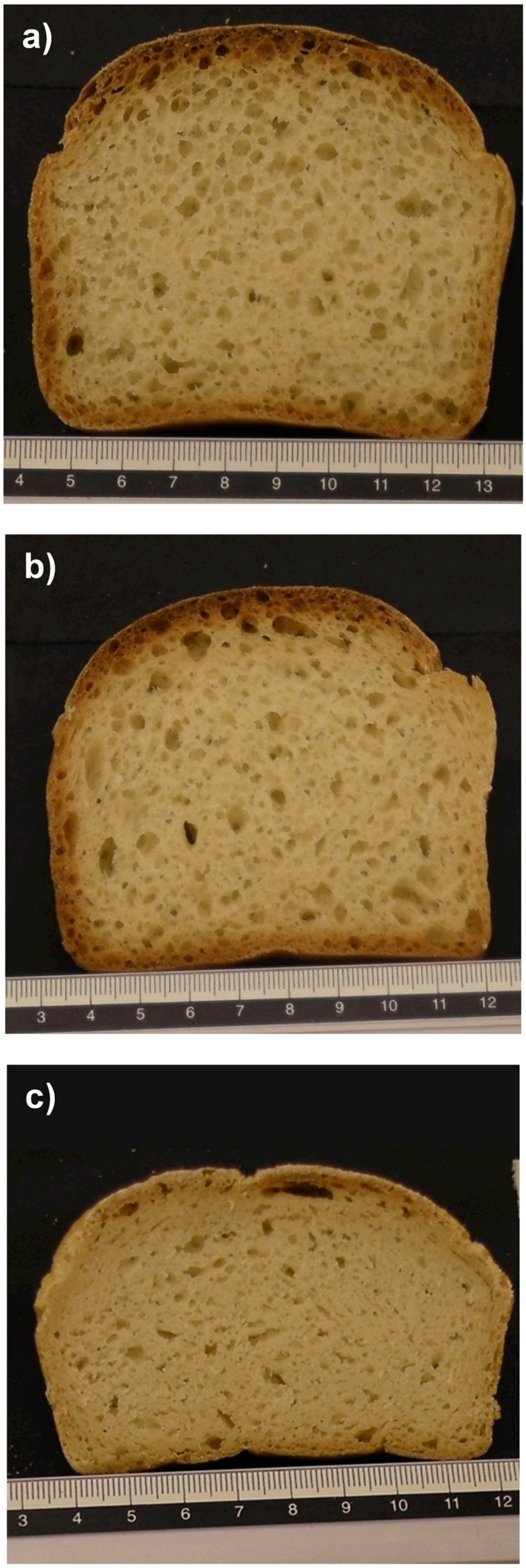

Fig. 2. Characteristic images of central slices of breads made with: a) untreated semolina (control), b) semolina treated at 120 °C (heat treatment B) for 30 min, c) semolina treated at 150 °C (heat treatment C) for 30 min.

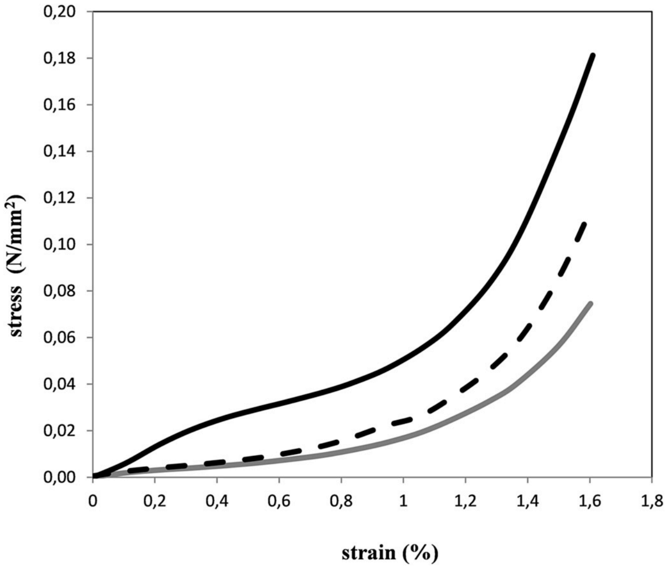

Fig. 3. Mean stress-strain curves for bread obtained from untreated (- - - control) and treated (- - -B and fx2 C) for 30 min semolina.

samples ($P < 0.05$). A decrease in gas bubble area to values of 26.7 ± 0.3% and 17.7 ± 1.5% was observed in bread slices obtained from semolina treated at 120 °C for 30 min and at 150 °C for 30 min, respectively. A significant decrease in the gas bubble area as compared to the control can be explained as the negative effect of a more intensive treatment (150 °C for 30 min), that reduces the ability of the gluten network to retain the carbon dioxide produced during the fermentation phase (Barak, Mudgil, & Khatkar, 2013).

Baking properties are affected by the quantity of the gluten present in the flour (Gomez, Ferrero, Calvelo, Anon, & Puppo, 2011), which plays an important role in determining both the crumb appearance and the firmness of cereal-based products (Demirkesen, Mert, Sumnu, & Sahin, 2010).

Fig. 3 shows the stress–Hencky strain curves of all bread crumb samples investigated. As expected, three zones can be distinguished for each curve: at low strain, the bread presented a linear elastic behavior, followed by a plateau zone where the stress was approximately constant, while finally a sharp increase of the stress was observed.

Linear elasticity is related to both cell wall bending and cell face stretching, in the presence of closed cells. In compressive loading, when a critical stress is reached, the cells begin to collapse and the plateau is reached. When most cells are collapsed, cell walls touch and further deformation compresses the cell wall material itself in a step known as densification (Gibson & Ashby, 1997).

Stress-strain curves of control and B bread samples differed mainly in the densification region, which starts at lower strain for B bread, reaching a higher degree of densification. The C bread sample presented a greater resistance across the studied deformation range. These results are consistent with the more compact crumb structure of the bread prepared with treated RM-semolina, especially C bread. Once again, the higher crumb resistance to deformation could be explained by the poor gluten quality and lower loaf volume (Cavella, Romano, Giancone, & Masi, 2008). Previous studies have reported the negative impact of heat treatment on gluten proteins (Barak et al., 2013), and that the bread quality can also be influenced by the rheological properties of the doughs (Gras, Carpenter, & Anderssen, 2000) as well as other components present in the wheat flour (Dowell et al., 2008; Edwards et al., 2007).

Mechanical behavior well fits ($R^2 = 0.999$) the mathematical model (Masi et al., 1997). In Table 3, the estimated parameters were reported for all the bread samples. The four parameters represent the elasticity modulus (k1), the yield stress (k1/k2), the Poisson modulus (ν) and the densification index (a), respectively. The C bread showed a k1 mean value of 71.52 kPa, which was significantly different from that of the control and B breads. A more drastic heat treatment negatively affected the dough consistency and the bubble size distribution of the crumb; as a consequence the elasticity modulus increased and the bread firmness increased (Di Monaco, Torrieri, Pepe, Masi, & Cavella, 2015; Pepe, Ventorino, Cavella, Fagnano, & Brugno, 2013).The mean k1/k2 ratio was equal to 0.076 in the control, and was lower in samples treated at 120 °C for 30 min (0.006), while it was higher after the treatment at 150 °C for 30 min (0.140). Neither the Poisson coefficient nor the densification index were very different among the three analyzed samples.

Visual and texture characteristics of the B bread obtained from the RM-semolina treated for 30 min were not significantly different from the control, as we have observed by the bubble area fraction and the mechanical properties.

Therefore this treatment can be suggested to reduce both mould development and the level of mycotoxins in semolina based products, for example in foodstuffs intended for children where the fixed limits for these contaminants are more restrictive, without having any negative impact on the technological properties.

4. Conclusions

Technological performances of RM-semolina submitted to heat treatment at different durations and temperatures were examined during the bread making process. On the basis of this work the following conclusions can be drawn.

For all cases investigated (A, B and C), the dough consistency increased while the maximum positive expansion of volume ratio was reached with 5 min of heat treatment. In particular, an improvement in the leavening phase of dough was obtained from the semolina thermally treated at 120 °C (B) for 30 min.

The quality of the bread obtained from the RM-semolina treated at 150 °C (C) for 30 min was impaired by high temperature, likely as a consequence of damage of the starch and gluten network.

We did not find any significant change in the quality of bread obtained from the RM-semolina treated at 120 °C for 30 min, as revealed by the moisture content, water activity, bubble size distribution and mechanical properties of the bread crumb, and so this treatment can be applied without exert undesirable effects on the technological properties.

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References

AACC International Approved Methods of Analysis (1999). *Method 02–52.01 (hydrogen ion activity (pH) Method), method 44–15.02 (moisture air-oven method)*. St. Paul, MN, U.S.A.

Barak, S., Mudgil, D., & Khatkar, B. S. (2013). Relationship of gliadin and glutenin proteins with dough rheology, flour pasting and bread making performance of wheat varieties. *LWT-Food Science and Technology, 51*, 211–217.

Cavazza, A., Corradini, C., Rinaldi, M., Salvadeo, P., Borromei, C., & Massini, R. (2013). Evaluation of pasta thermal treatment by determination of carbohydrates, furosine, and color indices. *Food and Bioprocess Technology, 6*, 2721–2731.

Cavella, S., Romano, A., Giancone, T., & Masi, P. (2008). The influence of dietary fibres on bubble development during bread making. In G. M. Campbell, M. G. Scanlon, & D. L. Pyle (Eds.). *Bubbles in food 2: Novelty, health and luxury* (pp. 311–321). St. Paul, MN, USA: Eagan Press.

Chiavaro, E., Vittadini, E., Musci, M., Bianchi, F., & Curti, E. (2008). Shelf-life stability of artisanally and industrially produced durum wheat sourdough bread ("Altamura bread"). *Lebensmittel-Wissenschaft und -Technologie- Food Science and Technology, 41*, 58–70.

Commission Regulation (EC) No 516/2009 of 17 (June 2009). (Pagnotta del Dittaino (PDO)). *Official Journal of the European Union L, 155*, 7–8. http://data.europa.eu/eli/reg/2009/516/oj Accessed 18. June 2009.

Correa, M. J., Pérez, G. T., & Ferrero, C. (2012). Pectins as breadmaking additives: Effect on dough rheology and bread quality. *Food and Bioprocess Technology, 5*, 2889–2898.

Demirkesen, L., Mert, B., Sumnu, G., & Sahin, S. (2010). Rheological properties of gluten-free bread formulations. *Journal of Food Engineering, 96*, 295–303.

Di Monaco, R., Torrieri, E., Pepe, O., Masi, P., & Cavella, S. (2015). Effect of sourdough with exopolysaccharide (EPS)-producing lactic acid bacteria (LAB) on sensory quality of bread during shelf life. *Food and Bioprocess Technology, 8*, 691–701.

Dowell, F. E., Maghirang, E. B., Pierce, R. O., Lookhart, G. L., Bean, S. R., Xie, F., et al. (2008). Relationship of bread quality to kernel, flour, and dough properties. *Cereal Chemistry, 85*, 82–91.

Edwards, N. M., Gianibelli, M. C., McCaig, T. N., Clarke, J. M., Ames, N. P., Larroque, O. R., & Dexter, J. E. (2007). Relationships between dough strength, polymeric protein quantity and composition for diverse durum wheat genotypes. *Journal of Cereal Science, 45*, 140–149.

Gao, J., Wong, J. X., Lim, J. C.-S., Henry, J., & Zhou, W. (2015). Influence of bread structure on human oral processing. *Journal of Food Engineering, 167*, 147–155.

Gibson, L. J., & Ashby, M. F. (1997). In C. A. Harper (Ed.). *Cellular solids: Structure and properties*(2nd ed.). New York, USA 0975: Mcgraw-Hill.

Gomez, A., Ferrero, C., Calvelo, A., Anon, M., & Puppo, M. (2011). Effect of mixing time on structural and rheological properties of wheat flour dough for breadmaking. *International Journal of Food Properties, 14*, 583–598.

Gras, P. W., Carpenter, H. C., & Anderssen, R. S. (2000). Modeling the development rheology of wheat flour dough using extension test. *Journal of Cereal Science, 31*, 1–13.

Hoseney, R. C. (1994). *Gluten proteins. Principles of Cereal Science and Technology*. St Paul, MN: American Association of Cereal Chemistry, Inc.

Keetels, C. J. A. M., van Vliet, T., & Walstra, P. (1996). Gelation and retrogradation of concentrated starch systems: 1 Gelation. *Food Hydrocolloids, 10*, 343–353.

Khatkar, B. S. (2006). Effects of high Mr glutenin subunits on dynamic rheological properties and bread making qualities of wheat gluten. *Journal of Food Science and Technology, 43*, 382–387.

Khatkar, B. S., Bell, A. E., & Schofield, J. D. (1995). The dynamic rheological properties of glutens and gluten sub-fractions from wheats of good and poor bread making quality. *Journal of Cereal Science, 22*, 29–44.

Mann, J., Schiedt, B., Baumann, A., Conde-Petit, B., & Vilgis, T. A. (2014). Effect of heat treatment on wheat dough rheology and wheat protein solubility. *Food Science and Technology International, 20*, 341–351.

Masi, P., Sepe, M., & Cavella, S. (1997). *Mathematical modelling of the compressive stress -strain relationship of foods submitted to large deformations. Engineering & Food at ICEF71. Engineering Food at ICEF7* Sheffield UK: Sheffield Academic Press212–215.

Meza, B. A., Chesterton, A. K. S., Verdini, R. A., Rubiolo, A. C., Sadd, P. A., Moggridge, G. D., et al. (2011). Rheological characterisation of cake batters generated by planetary mixing: Comparison between untreated and heat-treated wheat flours. *Journal of Food Engineering, 104*, 592–602.

Nakamura, C., Koshikawa, Y., & Seguchi, M. (2008). Increased volume of Kasutera Cake (Japanese Sponge Cake) by dry heating of wheat flour. *Food Science and Technology Research, 14*, 431–436.

Neill, G., Al-Muhtaseb, A. H., & Magee, T. R. A. (2012). Optimisation of time/temperature treatment, for heat treated soft wheat flour. *Journal of Food Engineering, 113*, 422–426.

Pasqualone, A. (2012). Italian durum wheat breads. In M. T. Pedrosa Silva Clerici (Ed.). *Bread consumption and health* (pp. 57–80). Hauppauge, NY (USA): Nova Science Publisher Inc978-1-62-081-090-3.

Pasqualone, A., Laddomada, B., Centomani, I., Paradiso, V. M., Minervini, D., Caponio, F., et al. (2017). Bread making aptitude of mixtures of re-milled semolina and selected durum wheat milling by-products. *Lebensmittel-Wissenschaft und -Technologie- Food Science and Technology, 78*, 151–159.

Pasqualone, A., Paradiso, V. M., Summo, C., Caponio, F., & Gomes, T. (2014). Influence of drying conditions on volatile compounds of pasta. *Food and Bioprocess Technology, 7*, 719–731.

Pepe, O., Ventorino, V., Cavella, S., Fagnano, M., & Brugno, R. (2013). Prebiotic content of bread prepared with flour from immature wheat grain and selected dextran-producing lactic acid bacteria. *Applied and Enviromental microbiology, 79*(12), 3779–3785.

Purhagen, J. K., Sjöö, M. E., & Eliasson, A. N. (2011). The use of normal and heat-treated barley flour and waxy barley starch as anti-staling agents in laboratory and industrial baking processes. *Journal of Food Engineering, 104*, 414–421.

Raffo, A., Pasqualone, A., Sinesio, F., Paoletti, F., Quaglia, G., & Simeone, R. (2003). Influence of durum wheat cultivar on the sensory profile and staling rate of Altamura bread. *European Food Research and Technology, 218*, 49–55.

Romano, A., Cavella, S., Toraldo, G., & Masi, P. (2013). 2D Structural imaging study of bubble evolution during leavening. *Food Research International, 50*, 324–329.

Romano, A., Giosafatto, C. V. L., Di Pierro, P., Romano, R., Masi, P., & Mariniello, L. (2016). Impact of transglutaminase treatment on properties and in vitro digestibility of white bean (Phaseolus vulgaris L.) flour. *Food Research International, 88*, 239–246.

Romano, A., Toraldo, G., Cavella, S., & Masi, P. (2007). Description of leavening of bread dough with mathematical modelling. *Journal of Food Engineering, 83*, 142–148.

Sahin, S. (2008). Cake batter rheology. In S. G. Sumnu, & S. Sahin (Eds.). *Food engineering aspects of baking sweet goods* (pp. 99–117). Florida, USA: CSR Press, Boca Raton.

Shanakhat, H., Sorrentino, A., Raiola, A., Reverberi, M., Salustri, M., Masi, P., et al. (2019). Technological properties of durum wheat semolina treated by heating and UV irradiation for reduction of mycotoxin content. *Journal of Food Process Engineering, 42*, 1–11. https://doi.org/10.1111/jfpe.13006.

Shibata, M., Sugiyama, J., Tsai, C. L., Tsuta, M., Fujita, K., Kokawa, M., et al. (2011). Evaluation of viscoelastic properties and air-bubble structure of bread containing gelatinized rice. *Procedia Food Science, 1*, 563–567.

Van Steertegem, B., Pareyt, B., Brijs, K., & Delcour, J. A. (2013). Impact of mixing time and sodium stearoyllactylate on gluten polymerization during baking of wheat flour dough. *Food Chemistry, 141*, 4179–4185.

Vidal, A., Sanchis, V., Ramos, A. J., & Marín, S. (2015). Thermal stability and kinetics of degradation of deoxynivalenol, deoxynivalenol conjugates and ochratoxin A during baking of wheat bakery products. *Food Chemistry, 178*, 276–286.

Wieser, H., Bushuk, W., & MacRitchie, F. (2006). *The polymeric glutenins. Gliadin and glutenin: The unique balance of wheat quality*. St. Paul American Association of Cereal Chemistry In this issue.