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Title

The effect of kneading speed on breadmaking from unrefined wheat flour dough

Authors

Ottavia Parenti*[1], Bruno Zanoni[2], Maria Rosaria Giuffrè[2], Lorenzo Guerrini[2]

1 Institute for Bioeconomy, National Research Council, Via Madonna del Piano 10, 50019 Sesto Fiorentino, Florence, Italy

2 Department of Agricultural, Food and Forestry Systems Management (DAGRI), University of Florence, Piazzale Delle Cascine 16, 50144, Florence, Italy

* Corresponding author. E-mail address: ottavia.parenti@unifi.it, tel +39 328 8336829, Institute for Bioeconomy, National Research Council, Via Madonna del Piano 10, 50019 Sesto Fiorentino, Florence, Italy

Abstract

The good nutritional value of unrefined wheat flours makes it necessary to implement breadmaking strategies to improve bread quality. The present study investigated the effect of kneading speed, dough water amount and kneading time on both the specific mechanical energy of unrefined wheat flour dough and the quality of unrefined wheat flour bread produced from two wheat flour cv. of different technological quality. The kneading speed turned out to be a critical factor to optimize the kneading operation. The effect of kneading speed was significantly linked with the kneading time and water amount as a function of the technological quality of flour. Advantageous operating conditions of kneading were also extrapolated to minimize both time and energy consumption of kneading, assuming 3.00 L/kg of bread specific volume as a reference value for soft bread: Application of high speed, short time and high dough water content was suggested for the kneading optimization for unrefined wheat flour.

Key words

Whole wheat flours; mixing; water amount; kneading time; wheat bread

1. Introduction

In recent years, the market demand for healthy food is constantly growing [1]. The interest in the use of unrefined wheat flours for breadmaking has also increased, since these flours show~~ed~~ a better chemical composition in terms of fibre, minerals, vitamins, and lipids than refined flours [2, 3]. Furthermore, scientific studies have reported that the regular consumption of unrefined flour-based food products is associated to positive effects on human health, by reducing the risk to develop cardiovascular diseases, type 2 diabetes, and some type of cancers [4, 5]. Although unrefined flours have an interesting nutritional profile, they show~~ed~~ poor breadmaking performance, resulting in sticky doughs difficult to work, and in low volume bread with coarse and hard texture, dark colour, nutty odour, and bitter/sour taste. In the literature, the most studied strategies to improve the breadmaking performance of unrefined flours involved treatments on milling by-products [6, 7], the addition of bread improvers such as enzymes, emulsifiers, hydrocolloids, and oxidants [8], and the use of the sourdough fermentation [9]. However, although both bakers and consumers are mainly interested in unrefined flour breads with clean label formulas [10, 11], ~~scant literature research~~ only limited information ~~was performed~~ is available on how to adjust ~~trying to change~~ the ~~breadmaking~~ operating conditions during breadmaking as a function of the inherent characteristics of raw materials [2].

Within the different unit operations of the breadmaking process, kneading represents one of the most important steps during which several phenomena occur to the dough constituents. A viscoelastic dough is obtained as a result of mixing of dough ingredients, proper hydration of ingredients, glass transition of amorphous regions of starch and amorphous proteins, gluten network development and inclusion of air bubbles within the dough structure [~~11, 12~~ 12, 13].

In the literature, it ~~was~~ has been reported that the appropriate control of the following kneading parameters significantly improved this operation: kneading time, dough temperature, the ~~speed of the~~ kneading speed ~~machine~~, dough aeration, flour water absorption, water temperature, and total water content [~~13~~ 14]. Considering the effect of the ~~speed of the~~ kneading speed ~~machine~~, a variable that changes the rate of energy supply to the developing dough [~~12~~ 13], the studies performed on refined wheat flours reported that to achieve the dough readiness, mixing intensity and the amount of work imparted to the dough should be above a minimum critical level, which changed as a function of the flour type [~~14–17~~ 15–18]. Increasing the ~~speed of~~ kneading speed ~~machine~~ resulted in significant effects on dough properties such as reduction of dough mixing stability [~~15, 18~~ 16, 19], increase of dough peak torque [~~19–21~~ 20–22], and decrease of the kneading time [~~15, 20, 22, 23~~ 16, 21, 23, 24]. Although the ~~speed of~~ kneading speed ~~machine~~ significantly impacted refined bread quality, few and contradictory effects were reported in the literature about this issue [~~14, 16, 22, 24, 25~~ 15, 17, 23, 25, 26].

Kneading can be considered even more critical for unrefined flour dough, since the presence of the fibres negatively affects the gluten network development [7]. Indeed, the unrefined flour doughs generally showed short dough stability at kneading and high dough weakening, as well as they are usually characterised by a high tenacity and low extensibility values [2, 3, 7]. However, only few studies tested the effect of kneading variables when the breadmaking was performed with unrefined flours [~~26–30~~ 27–31], and none of those papers evaluated the effect of changing the ~~speed of~~ kneading speed ~~machine~~.

Therefore, the aim of the present study was to investigate if the variation of kneading speed could help in overcoming the technological issues of using unrefined wheat flours in the breadmaking process. In detail, the effect of kneading speed, linked with the water amount and kneading time, was tested on both the specific mechanical energy (*SME*) of unrefined flour dough and the quality of unrefined flour bread produced from two wheat flour cv. of different technological quality.

2. Materials and Methods

2.1 Materials

Two batches of a sp. *Triticum aestivum* L., belonging to cv. Andriolo and Bologna, were used to perform the experimental trials. The wheat was grown in Montespertoli (Florence, Italy) during the 2020-2021 growing season. Brown flours (i.e., extraction rate 85 g/100 g dry kernel, ash content max 0.95 g/100 g dm [~~31~~ 32] were processed using a stone grinding mill and a sieve (two consecutive passages through 1,100-1,200 μm sieve) at the Molino Paciscopi (Montespertoli, Florence, Italy). According to the Farinograph and Alveograph characterisation reported in Table 1 and according to the literature [~~12~~ 32], Andriolo was the wheat flour of low technological quality, classified as weak or biscuit flour, whereas Bologna was the flour of good technological quality, classified as common breadmaking flour.

2.2 The experimental design

Baking trials, based on Doehlert Matrix (DM) Design [~~32~~ 33], were performed to test the effect of the following kneading variables: (i) Dough water amount – *W* (%, w/flour w), (ii) Kneading time – *T* (min), (iii) Kneading speed – *S* (rpm).

The DM Design allowed to investigate the effect of the 3 independent variables at different levels; 5 levels (- 1, - 0.5, 0, + 0.5, + 1) of *W* and *T*, and 3 levels of *S* (- 0.707, 0, + 0.707) were tested. The DM Design for 3 factors, of which 2 at 5 levels and one at 3 levels, required 16 experimental runs, including 4 replications of the centre point. A total of 16 experimental runs x 2 flour cv. resulted in 32 processed bread samples. Since two experimental trials were also performed to properly investigate Andriolo behaviour at kneading, the total number of processed bread samples was 32 + 16 = 48. The proper experimental range and distance levels of the tested variables were identified in preliminary trials; they were selected both to be approximately the same range for the tested flour cv. and to give bread moisture values which were consistent with Italian legislation [~~12~~ 34].

Experimental trials were divided in two blocks, performed on two consecutive days. Each block contained 8 trials; 6 trials were obtained by the randomization of the 16 variable combinations and 2 trials represented the centre points. The distance between 0 and +/- 1 points was 8% for the *W* variable, and 6 min for the *T* variable. The distance between 0 and +/- 0.707 was 50 rpm for the *S* variable. The response variables were the bread specific volume and the specific mechanical energy (*SME*) of dough.

2.3 Breadmaking

All the ingredients used to make bread were stored at room temperature (22 ± 2°C) and fresh brewer's yeast was stored at 4°C; 500 g batches of dough were prepared. The basic dough formula was brown flour (310 g), and fresh brewer's yeast (13 g); the amount of water was selected according to the DM Design. The kneading operation was performed at room temperature using a Kitchen Aid Professional Mixer (5KSM185PS, KitchenAid, St. Joseph, Michigan, USA) operating with a dough hook (model KSM35CDH) at the speed selected in the DM Design. After kneading, each dough was placed in a breadmaking machine (Pain doré, Moulinex, Ecully, France) to perform the proofing step for 90 min at room conditions (T = 22 ± 2°C, relative humidity = 50%), and baked at 150°C for 50 min.

2.4 Measurement methods

2.4.1 Dough rheology

The Brabender Farinograph test was performed according to the standard method (AACC 54–21.02). The following parameters were measured ~~[12]~~: water absorption (*WA*, % w/flour w) – the amount of water necessary to reach the reference of optimal dough consistency (500 BU); dough development time (*DDT*, min) – the time taken by the dough to reach the point of optimal dough consistency; dough stability (*DS*, min) – the time during which the dough consistency remained at the optimal value of 500 BU; mixing tolerance index (*MTI*, BU) – the difference between the peak of optimal dough consistency (500 BU) and the dough consistency measured 5 min after the peak; dough weakening (*DW*, BU) – the difference between the peak of optimal dough consistency (500 BU) and the dough consistency measured at the end of the assay (20 min) [~~12~~ 32].

The Alveograph test was performed following the standard method (AACC 54–30.02). The parameters measured were as follows ~~[33]~~: the dough tenacity (*P*, mm H_2O) – the maximum overpressure; dough extensibility (*L*, mm) – the average bubble length at rupture; swelling index (*G*, mm) – the square root of the volume of air necessary to inflate the dough bubble until it ruptures; flour strength (*W*, 10^{-4} J) – the energy required to inflate the dough bubble to the point of rupture; and ratio between dough tenacity and extensibility (*P/L*) [35].

2.4.2 Power consumption

The power consumption of dough samples was monitored every 5 s of kneading by means of an energy analyser (Fluke 434-II/435-II/437-II, Danaher Corporation, Everett, Washington, US). The parameters measured during kneading were electric current (A) – *I*, and voltage (V)

– *V*. Power consumption (W) was determined as the product between *I* and *V* (*I* x *V*), and total energy (kJ) was determined as the product between *V* and the kneading time – *T* (*V* x *T*). Dough specific mechanical energy – *SME* (kJ/kg) was determined as the ratio between the total energy imparted to the dough during kneading – *E* (kJ) and the mass of the dough (kg).

2.4.3 Bread quality

Bread volume (L) was measured using the standard millet displacement method (AACC 10-05.01), and bread specific volume (L/kg) was determined as the ratio between total bread volume (L) and its mass (kg).

2.5 Data processing

The response variables, bread specific volume and *SME*, were related with the tested variables by polynomial models using a multiple regression analysis (Standard Least Square Fitting). The significance of the tested variables was determined by ANOVA; it included first order (*W*, *T*, and *S*), second order (W^2, T^2, and S^2) coefficients, and their first order (*W*T*, *W*S*, *T*S*) and second order (*W*T*S*) interactions. Experimental data were processed with R software version 4.0.3.

3. Results

3.1 Specific mechanical energy (SME)

Dough *SME* of cv. Andriolo showed a significance of the first order ($p < 0.001$) and second order ($p < 0.05$) regression models. The minimum values of Andriolo dough *SME* ranged from a value of approx. 3.0 kJ/kg at 100 rpm to a value of approx. 3.5 kJ/kg at 150 rpm and

200 rpm, whereas its maximum value was approx. 9.0 kJ/kg at all the tested kneading speeds. Independently of kneading speed and water amount, the increase of the kneading time caused an increase of dough *SME*. The higher the water amount, the lower the *SME* of the dough, but the extent of *SME* decrease changed as a function of kneading time and speed. In particular, the lower the kneading speed and the longer the kneading time, the higher the decrease of dough *SME* as the water amount increased ~~as increasing the water amount~~. Up to 10 min of kneading time, a *SME* decrease of approx. 2.0-2.5 kJ/kg was observed at the medium (150 rpm) and lowest (100 rpm) kneading speed, whereas at the highest kneading speed (200 rpm) a lower *SME* decrease of approx. 1.0 kJ/kg occurred. In the kneading time ranging from 10 to 20 min, a dough *SME* decrease occurred with values of approx. 3.0 kJ/kg, 2.0-2.5 kJ/kg and 1.5 kJ/kg at the lowest, medium and highest kneading speeds, respectively.

Considering Bologna, results showed a significance of the first order regression model ($p < 0.001$). Values of the dough *SME* ranged from a minimum of approx. 2.0 kJ/kg to a maximum of approx. 8.5 kJ/kg at all the tested kneading speeds. An increase of the kneading time caused an increase of dough *SME*, and an increase of the water amount caused a decrease of *SME*. However, cv. Bologna dough had a different variation of *SME* as a function of both kneading speed and time; in particular, the lower the kneading time and speed, the higher the effect of water amount on the dough *SME*. Up to 16 min of kneading time, a *SME* decrease of approx. 1.5-2.0 kJ/kg was observed at 100 and 150 rpm kneading speed, whereas at 200 rpm kneading speed a lower *SME* decrease of approx. 1.0 kJ/kg occurred. In kneading time longer than 16 min, a dough *SME* decrease occurred with values of approx. 0.5-1.5 kJ/kg at 100 and 150 rpm and of 0.0-1.0 kJ/kg at 200 rpm.

3.2 Bread quality

The bread quality from cv. Andriolo dough showed a relationship with *W*, *T* and *S* variables. The surface plots at the three different kneading speeds are shown in Figure 1.

The first order coefficient of water amount (*W*) was significant (p < 0.001); regardless of kneading time and speed, the addition of different water amounts caused a variation of bread specific volume of approx. 0.50-0.60 L/kg, starting from values of approx. 2.50-2.60 L/kg and achieving values of approx. 3.00-3.10 L/kg. The second order coefficient of water amount (W^2) was also significant (p < 0.001); a maximum value of bread specific volume (3.00-3.10 L/kg) as a function of *W* was obtained at values of approx. 65.0-66.0%.

The interaction between kneading time and speed ($T*S$) had a significance of p < 0.05 and showed that effect of kneading time on bread specific volume changed as a function of kneading speed. After 5 min of kneading, the maximum bread specific volume was approx. 2.95 L/kg at 100 rpm, and 3.00 L/kg at both 150 rpm and 200 rpm. Instead, when kneading time increased, the bread specific volume showed the following different trend as a function of kneading speed: (i) at the lowest speed (100 rpm), bread specific volume gradually increased, reaching after 15 min of time a value of approx. 3.10 L/kg, which remained constant up to 20 min of kneading; (ii) at the medium speed (150 rpm), the maximum value of bread specific volume (3.05 L/kg) occurred after 6 min of kneading, remaining constant up to 19 min of kneading and then, decreasing; (iii) at the highest speed (200 rpm) the maximum bread specific volume (3.00 L/kg) was reached in the first few minutes of kneading, remaining constant up to 15 min of kneading and then, decreasing.

The bread quality from cv. Bologna dough showed a different behaviour compared to cv. Andriolo dough, as showed by the surface plots of at the three different kneading speeds (Figure 2). Although in the tested conditions the optimization of operating variables was not achieved, results showed that kneading variables significantly affected the quality of breads form cv. Bologna. The second order coefficients of water amount (*W^2*) and time (*T^2*) were significant ($p < 0.05$). The interaction between water amount and kneading speed (*W*S*) was significant (*p* < 0.05); the bread specific volume had a different trend at the tested kneading speeds as a function of the water amount. At the lowest speed and 15 min of kneading time, the bread specific volume showed a value of 2.80 L/kg when the water amount was low (55.5%); then, it started to increase showing values of 3.00 L/kg, 3.10 L/kg, 3.20 L/kg at 60%, 63% and 68% of water amount, respectively. The maximum value of 3.30 L/kg occurred close to the maximum levels of kneading time and water amount (i.e., 19-20 min and 69.0-71.5%).

At the medium speed and 15 min of kneading time, the bread specific volume was 2.70 L/kg when the water amount was low (55.5%), and then increased, reaching 3.00 L/kg, 3.10 L/kg, 3.20 L/kg, 3.30 L/kg at 61.0%, 63.0%, 66.5% and 71.5% of water amount, respectively. The maximum value of bread specific volume corresponded to 3.40 L/kg and it was achieved closed to the highest levels of kneading time and water amount (i.e., 20 min and 71.5%).

At the highest speed and 15 min of kneading time, the bread specific volume had a value of 2.70 L/kg when the water amount was low (55.5-56.5%), and then it increased in relation with the water amount increase, showing the following values: 3.00 L/kg at 61.0%, 3.10 L/kg at 63.0%, 3.20 L/kg at 65.0%, 3.30 at 67.5%, and 3.40 L/kg at 71.0%. The maximum value of bread specific volume corresponded to 3.40 L/kg and it was achieved at the highest kneading time (20 min) and water amount (71.5%) similarly to the results at the medium speed.

4. Discussion

4.1 The effect of kneading speed

Addition of flour improvers is usually proposed in the literature data [2, 3, 8] in order to process bread from unrefined wheat flours with acceptable technological quality. However, since consumers as well as bakers demand clean label breads, studies on adapting the processing conditions to the characteristics of raw materials are useful to improve the quality of unrefined flour bread, avoiding the use of improvers [10].

Water amount and kneading time have well known crucial roles during the wheat dough development [~~11–13, 17, 34~~ 12–14, 18, 36]. The water amount allows both the proper hydration of flour constituents and the glass transition of amorphous regions of starch and amorphous proteins [~~11, 12, 34~~ 12, 13, 36]. In unrefined wheat flour dough, the hydration of gluten proteins is reported to be hindered by the presence of fibre components, which compete with the gluten proteins for the water uptake; consequently, dough with poor tenacity to extensibility ratio and low bread volume are obtained [7, ~~12, 35~~ 13, 37]. Considering the effect of ~~T~~the kneading time, the determination of the optimal kneading time allows the optimal development of the gluten matrix, avoiding the detrimental effects of under- or over- kneading times [~~12, 34~~ 13, 36].

Our experimental data showed that also the kneading speed (*S*) significantly affected the quality of unrefined wheat flour bread, but the effect of kneading speed was linked with the kneading time (*T*) and water amount (*W*) as a function of the technological quality of flour.

The weak flour cv. Andriolo was significantly affected by the interaction *S***T*, which proved that an increase of kneading speed decreased the kneading time required to obtain similar bread specific volume; these results are consistent with those reported in the literature about refined wheat flours [~~15, 20, 22, 25~~ 16, 21, 23, 26]. Furthermore, the maximum value of bread specific volume occurred at the minimum kneading speed, suggesting that cv.

Andriolo achieved the optimal dough development at the lowest energy-input supply; the above behaviour was consistent with literature data about the low energy requirements of refined weak flours during the kneading operation [14, 24 15, 25].

Instead, the flour of good breadmaking quality, cv. Bologna, was significantly affected by the interaction *S**W*. For bread specific volumes up to 3.00 L/kg (i.e. an acceptable bread specific volume according to [12]), an increase of the kneading speed required an increase of the water amount in order to reach the same values of bread specific volume. Conversely, for bread specific volume ≥ 3.10 L/kg, the higher the kneading speed the lower the water amount in order to reach the same values of bread specific volume. Furthermore, the increase of kneading speed significantly enhanced bread specific volume from 3.30 L/kg to 3.50 L/kg, reaching the maximum value of bread specific volume (3.50 L/kg) at the highest kneading speed. Therefore, the interaction between the rate of energy-input supply and water amount may affect both the hydration kinetics of unrefined flour constituents and the development of gluten proteins.

4.2 An approach to choose the kneading operating conditions

4.2.1 Maximum and acceptable bread volume

Bread volume is considered the most representative parameter to evaluate the overall bread quality [12 38, 39]. In our study a maximum value of bread specific volume was obtained at different kneading operating conditions as a function of wheat flour technological quality (Table 2). Cv. Andriolo reached a maximum bread specific volume of 3.10 L/kg at the following kneading conditions: The lowest kneading speed (100 rpm), 66% of water amount and 17.5 min of kneading time which imparted to the dough 7.51 kJ/kg of *SME*. Instead, cv. Bologna reached a maximum bread specific volume of 3.50 L/kg at the highest kneading speed (200 rpm), 71.5% of water amount and 20 min of kneading time that corresponded to 8.14 kJ/kg of *SME*. The above differences between the tested flours were consistent with the literature about the effect of flour technological quality on the dough kneading requirements [~~12, 14, 24~~ 13, 15, 25]. The specific kneading conditions required by the tested flours can be associated to their different technological quality, that is their different quantity and quality of wheat gluten proteins. Cv. Bologna showed the highest values of kneading speed, water amount, kneading time and *SME* to achieve an optimal dough development, according to its good technological quality; conversely, the weak flour cv. Andriolo showed the lowest values of the above variables [~~12, 14, 24~~ 13, 15, 25].

According to the classification of Italian bakery products made with wheat flours of different refinement degrees as well as with flours enriched with different fractions of milling by-products (bran, germ, middlings, etc.) ~~literature data~~, a bread can be defined “soft” when values of bread specific volume ~~of approx.~~ are higher than 2.50-3.00 L/kg and values of bread moisture are higher than 15% ~~corresponded to light and soft bread~~, ~~largely appreciated by consumers~~ [~~12~~ 38]. All bread samples tested in the present study had a moisture higher than 15% (data not shown). As regard to bread specific volume, we considered the highest value of the reported range, ~~If~~ i.e. 3.00 L/kg, ~~is assumed~~ as ~~an~~ the minimum threshold for acceptable bread specific volume~~,~~ . Following this criterion, a great~~er~~ number of suitable combinations of dough water amount, kneading time and speed can be chosen from the experimental data (Table 3). For cv. Bologna, when the dough water amount was approx. above 61%, all tested time and speed conditions of kneading were able to develop ~~acceptable~~ bread specific volumes ~~above~~ equal or higher than the selected ~~a specific~~ threshold of bread acceptability~~ of the~~ ~~dough water amount (approx. 61%);~~ . ~~t~~The corresponding dough *SME* ranged between 2.0 kJ/kg and 8.5 kJ/kg depending on both kneading time and water amount. Cv. Andriolo was more sensitive to kneading operating conditions than cv. Bologna, due to its low technological quality. The threshold of the dough water amount was approx. 62%, which were able to develop acceptable bread specific volume at suitable combinations of kneading time and speed as follows: 7-20 min, 4-20 min, 4-15 min at 100 rpm, 150 rpm, 200 rpm, respectively. The corresponding dough *SME* changed as a function of kneading speed, with values approx. in the range of 3.0-8.5 kJ/kg, 3.5-8.5 kJ/kg, and 3.5-7.0 kJ/kg at 100 rpm, 150 rpm and 200 rpm, respectively.

4.2.2 Advantageous operating conditions of kneading

~~An acceptable bread specific volume in the shortest kneading time was used as a criterion of an advantageous kneading~~. Advantageous kneading conditions were identified as the conditions that allowed to obtain a bread specific volume equal or higher than the selected threshold of bread acceptability (3.00 L/kg) in the shortest kneading time. Bread samples from cv. Andriolo unrefined flour reached the value of 3.00 L/kg after 4 min of kneading at both 150 rpm and 200 rpm (Table 3). However, whereas a quite careful evaluation of dough water amount (62.5-65%) was required at 150 rpm, the widest range of water amounts (60.5-68%) resulted in an unvaried bread specific volume at the highest kneading speed (200 rpm). Therefore, the choice of 200 rpm kneading speed allowed to obtain an acceptable bread volume in only 4 min of kneading time, without the necessity to carry~~ied~~ out an accurate determination of dough water amounts. Bread samples from cv. Bologna unrefined flour showed a different trend. A bread specific volume of 3.00 L/kg occurred with a kneading time of 8 min, independently of the kneading speed; the specific range of water amounts of ~~(~~approx. 62-72%~~)~~ resulted in an unvaried bread specific volume at all tested kneading speeds (Table 3). Therefore, cv. Bologna was able to reach an acceptable bread volume at all tested speeds in a similar and wide range of water amounts values, which should be above a minimum value of 62%.

The above advantageous operating conditions were also consistent with the ~~environmental impact~~ ~~of~~ energy consumption associated to the kneading operation, because they were able to ~~cause~~ produce an acceptable bread specific volume with the lowest values of energy consumption. For cv. Andriolo, 200 rpm for 4 min of kneading time was a good combination of variables ~~for the acceptable~~ resulting in bread specific volume equal or higher than the selected threshold (3.00 L/kg) of product acceptability and requiring ~~with~~ the lowest *SME*, ~~ranging~~ which ranged from approx. 3.7 to 4.2 kJ/kg as a function of dough water amount. The highest values of *SME* were obtained at the other kneading speeds (i.e., 4.0-4.5 kJ/kg at both 100 and 150 rpm). For cv. Bologna, the minimum value of *SME*, which was approx. 2.0 kJ/kg, was obtained at the highest water amount (71.5%) and at the minimum kneading time of 8 min, independently of the kneading speed. However, the highest mixing speed (200 rpm) can be considered the best operating condition to minimize the energy requirements, because the lowest range of *SME* values (2.0-3.0 kJ/kg) was also obtained independently of the water amount; a greater range of *SME* value was obtained as a function of water amount at both the minimum (2.0-4.0 kJ/kg) and medium (2.0-3.5 kJ/kg) kneading speed.

5. Conclusions

The originality of this paper is that the combined effect of kneading speed with kneading time and dough water amount was studied in order to improve the quality of bread from unrefined wheat flour dough. Experimental data showed that a suitable choice of the above kneading operating conditions allows an optimization of bread specific volume as a function of the technological quality of unrefined wheat flour.

The kneading speed was a critical factor to optimize the kneading operation. A significant relationship between kneading speed and time resulted for the weak flour cv. Andriolo: Increase of the kneading speed decreased the kneading time to obtain high values of bread specific volume. Instead, a significant relationship between kneading speed and dough water amount resulted for the cv. Bologna flour (i.e. a common breadmaking flour): The greater the kneading speed, the lower the dough water requirements to obtain high values of bread specific volume. Advantageous operating conditions of kneading were also extrapolated in order to minimize both time and energy consumption (i.e., *SME* values) of kneading, assuming 3.00 L/kg of bread specific volume as ~~a reference value for soft~~ the acceptability threshold for unrefined flour bread; kneading optimization for unrefined wheat flour may be reached applying high speed, short time and high dough water content conditions.

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Figure captions

Figure 1. Contour plots obtained from the Response Surface Methodology for cv. Andriolo unrefined wheat flour. Estimation of bread specific volume was evaluated within the whole selected range of kneading time (4-20 min) and water amount (55.5-71.5%) at the three different kneading speeds: a) 100 rpm, b) 150 rpm and c) 200 rpm. Black lines represent points of the surface with the same bread specific volume.

Figure 2. Contour plots obtained from the Response Surface Methodology for cv. Bologna unrefined wheat flour. Estimation of bread specific volume was evaluated within the whole selected range of kneading time (8-20 min) and water amount (55.5-71.5%) at the three different kneading speeds: a) 100 rpm, b) 150 rpm and c) 200 rpm. Black lines represent points of the surface with the same bread specific volume.

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Conflict of interest/Competing interests

Please check the following as appropriate:

- ✓ ☒ The All authors have participated in (a) conception and design, or analysis and interpretation of the data; (b) drafting the article or revising it critically for important intellectual content; and (c) approval of the final version.

- ✓ ☒ The This manuscript has not been submitted to, nor is under review at, another journal or other publishing venue.

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- ✓ ☐ The The following authors have affiliations with organizations with direct or indirect financial interest in the subject matter discussed in the manuscript:

Authors's name	**Affiliation**
Ottavia	Institute for Bioeconomy, National Research Council, Via Madonna del

Parenti	Piano 10, 50019 Sesto Fiorentino, Florence, Italy
Bruno Zanoni	Department of Agricultural, Food and Forestry Systems Management (DAGRI), University of Florence, Piazzale Delle Cascine 16, 50144, Florence, Italy
Maria Rosaria Giuffrè	Department of Agricultural, Food and Forestry Systems Management (DAGRI), University of Florence, Piazzale Delle Cascine 16, 50144, Florence, Italy
Lorenzo Guerrini	Department of Agricultural, Food and Forestry Systems Management (DAGRI), University of Florence, Piazzale Delle Cascine 16, 50144, Florence, Italy

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Code availability

Not appliable

Authors' contributions

Conceptualisation (Lorenzo Guerrini), Formal analysis (Lorenzo Guerrini), Funding acquisition (Lorenzo Guerrini, Bruno Zanoni), Investigation (Ottavia Parenti, Maria Rosaria Giuffrè), Methodology (Lorenzo Guerrini), Project administration (Lorenzo Guerrini, Bruno Zanoni), Resources (Lorenzo Guerrini, Bruno Zanoni), Software (Lorenzo Guerrini), Supervision (Lorenzo Guerrini, Bruno Zanoni), Writing- original draft (Ottavia

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Table 1 Rheological characterisation of cv. Andriolo and cv. Bologna flour samples.

Farinograph Parameter	**Sample**	
	cv. Bologna	**cv. Andriolo**
WA (%)	59.0	57.5
DDT (min)	3.5	2.0
DS (min)	9.0	3.0
MTI (BU)	0	65
DW (BU)	50	145
Alveograph parameter	**Sample**	
	cv. Bologna	**cv. Andriolo**
P (mm H_2O*)*	104.2 ± 4.9	67.1 ± 3.5
L (mm)	38.2 ± 4.1	27.1 ± 1.6
G (mm)	13.8 ± 0.8	11.6 ± 0.3
W (10^{-4} *J)*	163.2 ± 8.1	75.0 ± 1.4
P/L	2.8 ± 0.4	2.5 ± 0.3

Farinograph parameters: water absorption – *WA* (%), dough development time – *DDT* (min), dough stability – *DS* (min), mixing tolerance index – *MTI* (BU), dough weakening – *DW* (BU). Alveograph parameters: dough tenacity – *P* (mm H_2O), dough extensibility – *L* (mm), flour strength – *W* (10^{-4} J), tenacity to extensibility ratio – *P/L*.

Table 2 Experimental kneading operating conditions and specific mechanical energy that resulted in the maximum bread specific volume for cv. Andriolo and cv. Bologna flour samples.

Sample	Dough water amount* (%)	Kneading time (min)	Kneading speed (rpm)	Specific mechanical energy (kJ/kg)	Bread specific volume (L/kg)
cv. Andriolo	66.0	17.5	100	7.51	3.10
cv. Bologna	71.5	20.0	200	8.14	3.50

* The dough water amount (% - w/flour w)

Table 3 Kneading operating conditions to obtain an acceptable bread specific volume quality (bread specific volume = 3.00 L/kg according to which was defined as a specific volume equal or higher than the maximum value of the acceptability range reported by [38] (i.e., 2.50-3.0 L/kg) Zhou, Therdthai, & Hui, (2014).

Sample	Kneading speed (rpm)	Kneading time (min)	Time range ΔT (min)	Dough water amount* (%)	Dough water range ΔW (%)
cv. Andriolo	100	7-20	12	62.5-65.0	2.5
	150	4-20	16	62.5-65.0	2.5
	200	4-16	12	60.5-68.0	7.5
cv. Bologna	100	8-20	12	60.5-71.5	16.0
	150	8-20	12	61.0-71.5	15.0
	200	8-20	12	61.5-71.5	14.0

* The dough water amount (% - w/flour w)

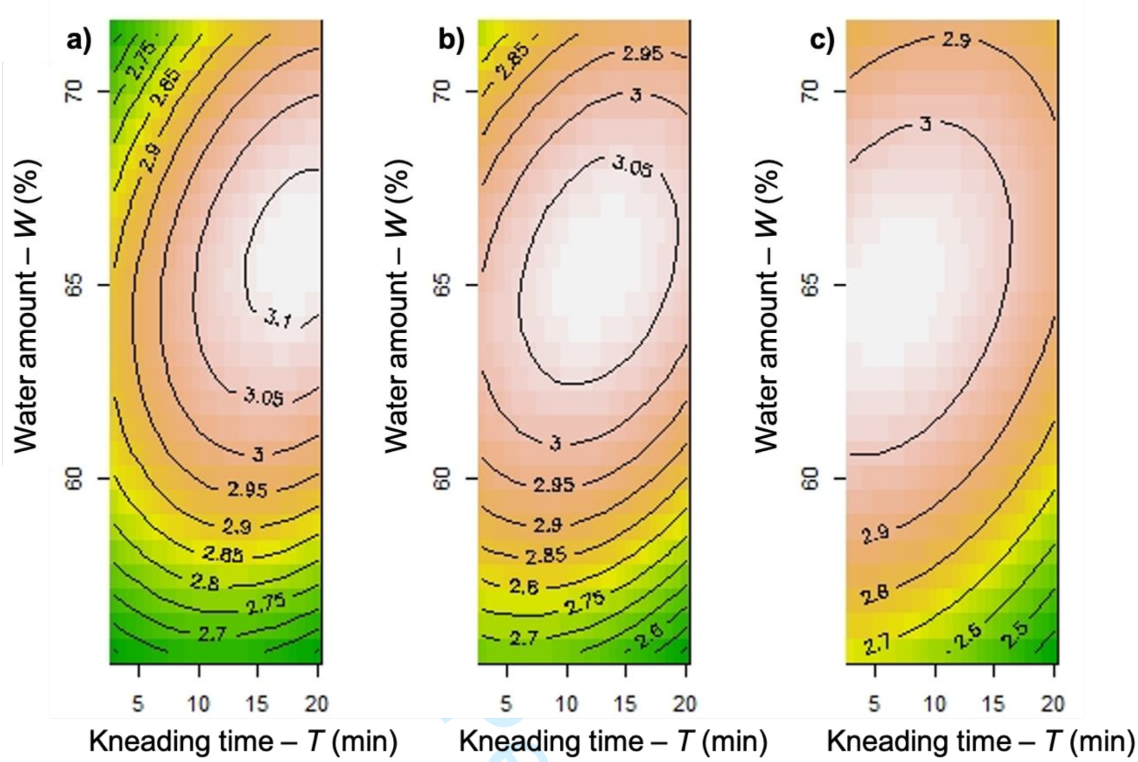
a)
b)
c)
Water amount – W (%)
Kneading time – T (min)
5
10
15
20
60
65
70
2.7
2.75
2.8
2.85
2.9
2.95
3
3.05
3.1
2.65
2.6
2.5

Figure 1.

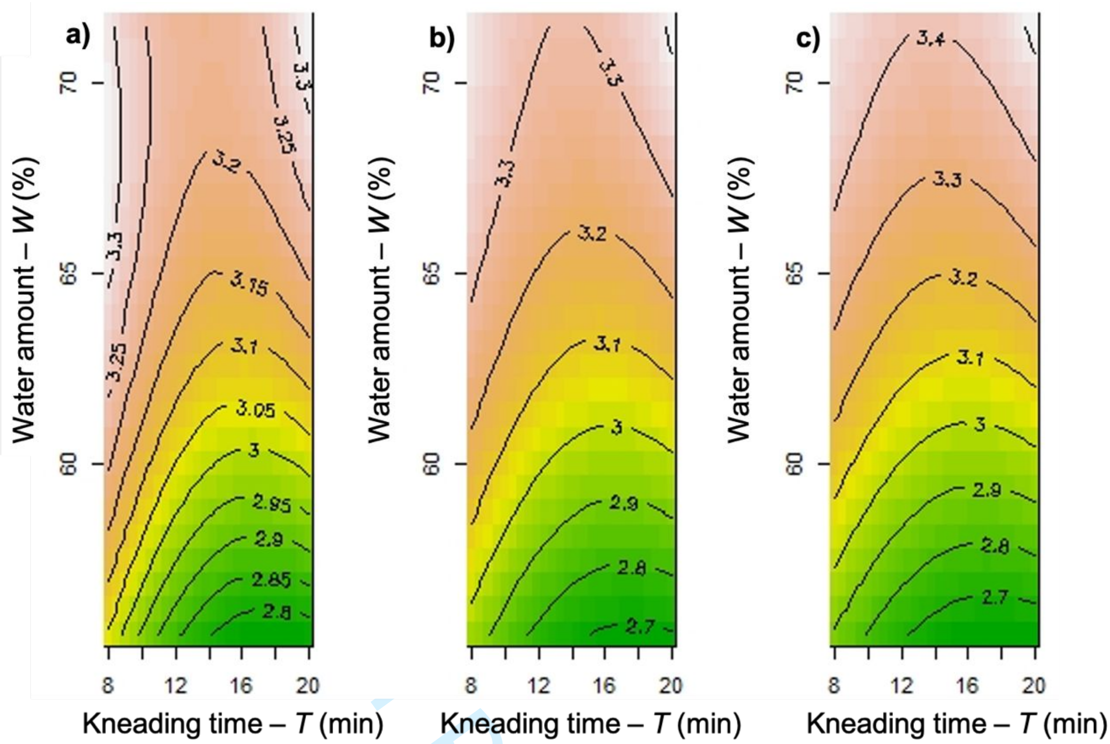
a)
b)
c)
Water amount – W (%)
Kneading time – T (min)
70
65
60
8
12
16
20
3.3
3.25
3.2
3.15
3.1
3.05
3
2.95
2.9
2.85
2.8
3.2
3.1
2.9
2.8
2.7
3.4
3.3
3.2
3.1
3
2.9
2.8
2.7

Figure 2.