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Durum Wheat Dough Torque Measurements: Characterization and Study of the Mixing Process Parameters as a Function of Water and Salt Amounts

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Different physicochemical phenomena are involved in breadmaking, which produce perceptible changes in the rheological properties of dough. In this regard, the kneading phase is crucial for the assessment of the quality of the final product. Indeed, the determination of the optimal time in the mixing process allows to optimize the rheological properties of the dough and the energy consumption. In this work, torque measurements were carried out on durum wheat commercial semolina using a Brabender Mixer 350 (Brabender® GmbH, Duisburg, D) where semolina was mixed with water in different amounts (from 40% to 60% of semolina weight). Each sample was mixed for 20 minutes. The salt effect was instead investigated by adding a variable amount of salt (from 0% to 2.5% of semolina weight). The optimal mixing time value, which occurs at the maximum torque value, was determined and studied with respect to salt and water quantity. Additionally, spectrograms of the torque time series data were computed in order to provide the magnitude (and frequency) of the torque oscillations with time. The results showed a significant influence of water amount on the torque maximum value and on the mixing time, with the latter that linearly depends on water amount. Also, the amplitude oscillations resulted to be related to the water amount, as their amplitude decreases when the water amount increases. On the other hand, the salt effect is less evident but an influence on optimal mixing time is however detected.

1. Introduction

The kneading process is crucial for the establishment of the rheological properties of dough since it promotes the gluten network development in addition to allowing the mixing of the ingredients and the formation of a homogeneous and coherent mass (Fanari et al., 2020a). In mixing and kneading, the dough is stretched through the application of mechanical energy (Zheng et al., 2000). Such energy allows different conformational arrangements of the key biopolymers (particularly gluten proteins) which are present in the system and promotes interactions among the constituents (proteins, starch, and water) of the dough (Fanari et al., 2020b), leading to a three-dimensional gluten network structure, in which the starch globules are embedded (Park et al., 2009). This network is responsible for the viscoelastic properties of the dough and determines its machining properties and the final quality of the product (Contamine et al., 1995). Mixing time significantly affects the structures of the gluten networks in wheat doughs, which in turn can influence the dough baking quality. Cappelli et al. (Cappelli et al., 2020) recently wrote a review about the kneading process in breadmaking. In this work, they state that the identification, study, and comprehension of the key process parameters are the first steps to achieve in order to improve the quality of the final product.

To study the kneading process and related changes in dough rheological properties, torque measurements can be used to quantify the strength opposed by the dough as a function of time. These measurements are empirical and follow the same basic principle, that is, the resistance opposed by the dough at the kneader shaft is transferred to a dynamometer and recorded. Torque curves provide information about the rheological

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characteristics of dough on which the quality of the flour is usually evaluated. Additionally, from this curve, it is possible to find other interesting parameters, depending on the device used for the measurement: time of formation or development of the dough, time of stability, maximum degree of softening of the dough, dough elasticity, hydration capacity, and flour strength (Miś et al., 2012). These parameters are useful to optimize formulations for baking quality especially in terms of determining the optimum water amount for a specific kind of flour, optimizing the time of mixing to obtain a well-developed dough with optimal rheology and gas holding capacity (Yazar et al., 2016). Optimal mixing time is the time required for the optimal development of the dough, which occurs when the gluten fibrils spread into a 3D network encompassing the whole dough mass. This value is determined as the maximum of the torque curve, which also corresponds to the maximum dough strength (Watanabe et al., 1992). It is commonly assumed that the mechanical work input (i.e. mixing energy) is the most significant factor affecting the optimal dough development, together with the mixing time length (Baudouin et al., 2020). It was observed that an increase in the protein amount leads, in general, to a decrease in the optimal mixing time (Munteanu et al., 2016). Depending on the strength of the flour, the curve can present a maximum defined as a peak or as a plateau. For times longer than the optimal mixing time, a decrease in the mixing curve is usually observed. This feature is due to the breakdown of the gluten protein network. The network is held together by secondary bonding interactions which are susceptible to breakdown when subjected to high strains (Amemiya & Menjivar, 1992) and, at the same time, the starch granules appear to get more space to move in the dough matrix (Li et al., 2020). In industrial bakery plants, a common practice is to adjust the mixing time according to the mixing speed in order to deliver the specified amount of mechanical energy (Baudouin et al., 2020). If the aim is to improve dough rheology and resulting bread characteristics, the most important requirements are to select the best kneading machine, to manage the addition of water (quantity and temperature), and to select the most suitable improvers (organic acid, NaCl substitute, enzymes, hydrocolloids, and/or emulsifiers) (Cappelli et al., 2020). This should be evaluated on a case-by-case basis, according to the kind of product at issue.

To summarize, it is possible to state that the quality of bread and bakery products dough strongly depends on the mixing conditions (mixer type, rotation speed, and mixing time), on the and water content, on the characteristics of the used flour (Ortolan & Steel, 2017) and, to a lesser extent, on the other ingredients and additives mixed in the dough (Fanari et al., 2019a; 2019b). The aim of the present study is to characterize the dough during mixing by torque measurements and, subsequently, to address empirical modelling of the mechanical properties varying during the process. The study is focused on durum wheat commercial semolina used in the production of a typical Sardinian bread named “Pani Carasau”.

2. Materials and methods

Each dough sample was prepared by mixing 300 g of commercial semolina with distilled water and salt (when added) in a Brabender Measuring Mixer 350 (Brabender® GmbH, Duisburg, D) for 20 min, using a rotational mixing speed of 20 rpm. The value of 20 rpm was chosen to avoid important structure breaks in the dough structure. In Table 1 the properties of the semolina used in the work are reported. To study the water effect on the dough, semolina was mixed with water in different amounts (40%, 45%, 50%, 55%, and 60% of semolina weight).

Table 1: Properties of semolina used in this study

	Proteins (%)	Carbohydrates (%)	Fats (%)
Commercial Semolina	12.0	69.0 (0.8 are sugars)	0.8

To study the salt effect, on the other side, the dough was prepared using an amount of water equal to 50% of the semolina weight and a variable amount of salt (0.5%, 1.0%, 1.5%, 2.0%, and 2.5% of the semolina weight). These samples were compared with W50 sample taken as reference sample (50% water and 0% salt). Table 2 reports the mass percentage of ingredients with respect to the semolina weight of the samples and their identification acronym. For each sample, three replicate measurements were performed, and the mean value was considered for the study.

The torque curves obtained by the measurements were filtered with a wavelet decomposition using order 5 Daubechies wavelets (Daubechies, 1992). The optimal mixing time value was evaluated as the time corresponding to the maximum torque value, finding the maximum of the smoothed curve for each sample. These values were analysed as a function of water and salt content to quantify their impact.

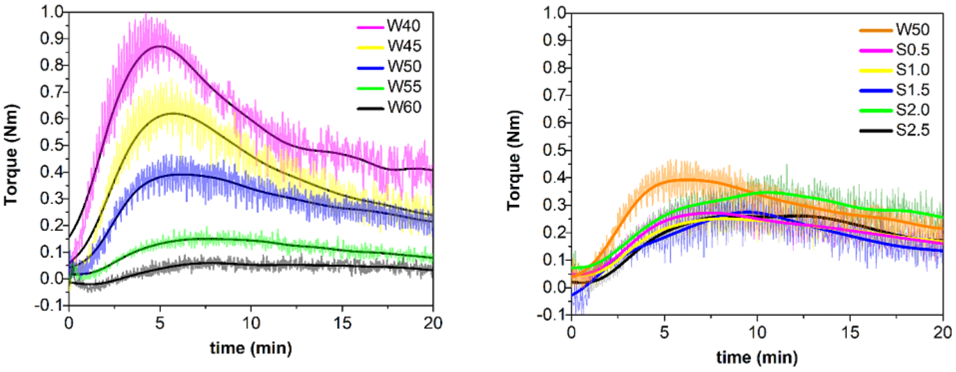
Additionally, spectrograms were carried out on the residuals of the time series data obtained as the differences between original raw data and the filtered ones. The spectrogram is a visual representation of the time evolution of the signal power spectrum. A Fourier Transform is applied on finite windows of the signal, deriving a time-localized estimation of amplitude and frequency. For details on the method see, for example, the work by Flandrin (1989). With this procedure, it is then possible to evaluate the amplitude of the oscillations and the related frequencies as a function of time.

Table 2: Samples percentage composition referred to semolina weight

	Water (%)	Salt (%)
W40	40.0	0.0
W45	45.0	0.0
W50	50.0	0.0
W55	55.0	0.0
W60	60.0	0.0
S0.5	50.0	0.5
S1.0	50.0	1.0
S1.5	50.0	1.5
S2.0	50.0	2.0
S2.5	50.0	2.5

3. Results

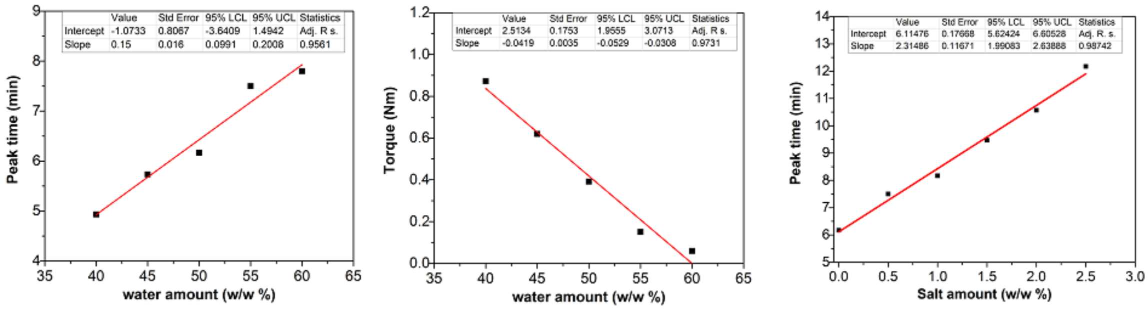
Figure 1 shows the comparison between torque curves and smoothed curves for samples with different water amount (Figure 1a) and samples with the same water amount, but different amount of salt (Figure 1b).



(a) *(b)*

Figure 1: Torque curves comparison among samples with different water (smoothed curves are represented as black lines) (a) and salt amounts (smoothed curves are represented as reported in the legend) (b)

Data smoothing is necessary to address an average trend of the torque, removing the oscillations that obstacle the identification of the maximum torque points. Results are shown in Table 3, where the peak time and the corresponding values of maximum torque, calculated for the smoothed curves, are reported in columns 3 and 2, respectively. Figure 2 shows the parameters peak time and torque as a function of water content (Figures 2a and 2b) and the peak time as a function of salt amount (Figure 2c). The maximum strength (corresponding to the maximum torque value) decreases with the water amount, whereas the peak time increases. The peak time can be modelled with a linear dependence on the water content. Results of the linear regression are reported with the red line in Figure 2a (R^2_{adj} = 0.956, p-value = $3{\cdot}10^{-3}$). Maximum torque also shows a linear dependence on the water content (R^2_{adj} = 0.973, p-value = $2{\cdot}10^{-3}$) but with a negative slope (red line on Figure 2b). On the other hand, salt addition results in a linear increase of the peak time (R^2_{adj} = 0.987, p-value = $4{\cdot}10^{-5}$) when added up to 2.5% (Figure 2c). Regarding torque values, the addition of salt produces a variable decrease, according to the added quantity and, in general, the magnitude of these effects is lower compared to water induced effects.



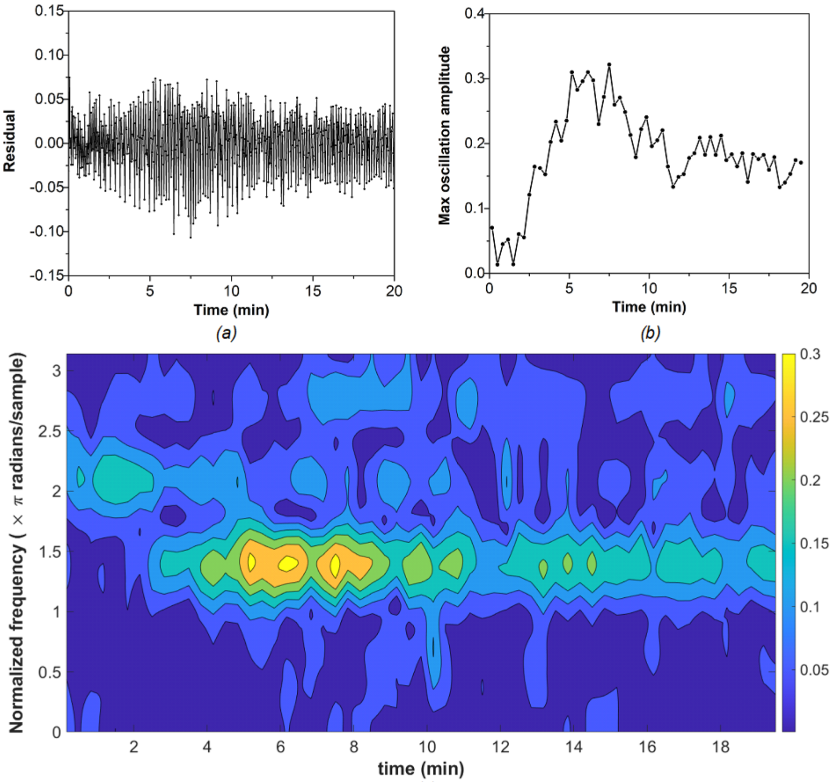
(a) *(b)* *(c)*

Figure 2: Peak time (a) and maximum torque (b), calculated from the smoothed torque curves, as a function of water amount in the dough (percentages based on semolina weight); peak time (c) as a function of salt content; the red line is the linear regression model; in the tables above, the statistical parameters of the regression Standard error (Std Error), 95% Lower Confidence Limit (LCL) and Upper confidence Limit (UCL), and Adjusted R^2 (Adj R.s.), are reported

Table 3: Maximum torque, peak times, oscillation amplitude and their relative peak times

Sample	Max torque (Nm)	Corresponding peak time (min)	Max oscillation amplitude peak (Nm)	Corresponding peak time (min)
W40	0.872	4.9	0.573	3.2
W45	0.620	5.7	0.485	4.2
W50	0.392	6.2	0.284	6.5
W55	0.150	7.4	0.114	7.2
W60	0.059	7.8	0.036	8.8
S0.5	0.272	7.5	0.240	7.2
S1.0	0.251	8.2	0.223	7.2
S1.5	0.275	9.5	0.331	6.8
S2.0	0.346	10.6	0.265	10.8
S2.5	0.268	8.6	0.255	11.2

Concerning the analysis of the oscillations, Figure 3a reports the residuals computed for the reference sample (W50). Such residuals are the differences between the experimental data and their projections onto the smoothed curve, thus giving an estimation of the actual oscillation that the torque is experiencing around its mobile average value. For the case shown here, one can see that oscillations are more pronounced at t ~ 7 min (near the optimal mixing time) and then they slightly decrease with time. This behavior is more apparent in Figure 3b, where the maximum oscillation amplitudes, evaluated with the spectrogram at the maximum frequency, are reported as a function of time. Therefore, values of maximum oscillation amplitude and the corresponding peak time for all the samples are reported in Table 3 (columns 4-5). As it is possible to observe from data in Table 3, for some samples the maximum oscillation amplitude and maximum torque occur approximately at the same values reported in Figure 2. The time at which the maximum oscillations occur increases as water amount increases (p-value equal to $6\cdot10^{-4}$, $R^2_{adj} = 0.982$), as shown in Figure 4a. Oscillation amplitudes, on the contrary, decrease with the water amount in the dough, following a linear trend (p-value equal to $2\cdot10^{-3}$, $R^2_{adj} = 0.964$), as shown in Figure 4b. These results are analogue to those reported above for torque peaks and relative times. Regarding salt, on the other hand, there is no structure in the data, probably due to its less significant impact on the mixing parameters. Despite this, the peak time at which the maximum oscillation amplitudes occur still increases as a function of the salt amount in the dough, as shown in Figure 4c. A linear model reasonably describes the dependence ($R^2_{adj} = 0.83$, p-value = $7\cdot10^{-3}$) thus confirming that maximum oscillation amplitude significantly increases with the salt amount. A visual inspection of the spectrograms seems to suggest that other peaks in maximum oscillation amplitude may occur at a time higher than the optimal mixing time (around 10-15 min depending on the sample). However, their exact quantification is not reliable, at least for the experimental data here considered. This second peak is more evident for samples with high amounts of water or salt which have a broader peak in the torque curve.

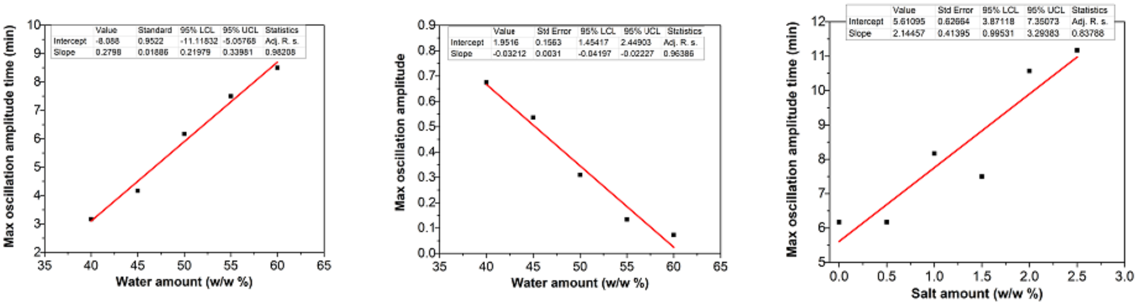


(a)

(b)

(c)

Figure 3: Statistical residuals (a), maximum oscillation amplitudes (b), and oscillation spectrogram (c) as a function of time, for W50 sample



	Value	Standard	95% LCL	95% UCL	Statistics
Intercept	-8.088	0.9522	-11.11832	-5.05768	Adj. R. s.
Slope	0.2798	0.01886	0.21979	0.33981	0.98208

	Value	Std Error	95% LCL	95% UCL	Statistics
Intercept	1.9516	0.1563	1.45417	2.44903	Adj. R. s.
Slope	-0.03212	0.0031	-0.04197	-0.02227	0.96386

	Value	Std Error	95% LCL	95% UCL	Statistics
Intercept	5.61095	0.62664	3.87118	7.35073	Adj. R. s.
Slope	2.14457	0.41395	0.99531	3.29383	0.83788

(a)

(b)

(c)

Figure 4: Peak time (a) and relative maximum oscillations amplitude (b), as a function of water amount in the dough (percentages based on semolina weight); maximum oscillation corresponding time (c) as a function of salt content; the red line is the linear regression model; in the tables above, the statistical parameters of the regression Standard error (Std Error), 95% Lower Confidence Limit (LCL) and Upper confidence Limit (UCL), and Adjusted R^2 (Adj R.s.), are reported

4. Discussion and Conclusions

This works aimed to quantify the impact of salt and water addition on the mixing properties of dough, with particular regard to optimal mixing time and maximum dough strength. Water amount in the dough very significantly affects the optimal mixing time (it linearly increases as a function of water amount) and the maximum strength of dough (that linearly decreases with water amount). Increasing water amount in the dough increases the percentage of free water on it. This is likely responsible for its viscosity decrease and for the increase in mixing time due to the extension of the hydration process. The linear relationship which was found can be used to predict the dough mixing parameters starting with the water amount added to it. Moreover, looking at the oscillation amplitudes, it is possible to state that they decrease as water amount increases, due to the reduction of the dough strength, while the time at which they are higher increases, in analogy with torque peak time. Additionally, it was observed also another peak in amplitude oscillations at times higher than optimal mixing time. This probably can be explained as a consequence of structure break and rebuild following the dough overmixing. Concerning the salt effect, it is possible to state that its influence on peak time is significant while the influence on dough strength and on torque oscillations does not follow a specific trend and it is not very significant in most cases. When salt is added up to 2%, the peak time increases almost linearly. This is due to the ability of salt to slow the protein hydration process, as reported by McCann and Day (2013). This phenomenon is observable also from the homogenization of the amplitude oscillations that, for these samples, appear more concentrated around the optimal mixing time, so the dough seems to suffer the overmixing effects to a lesser extent. As a future work development, it would be interesting to test the same procedure with different kinds of flour and see if the modelling and the estimation of the parameters are applicable also in other cases. Moreover, the methodology could be applied to an industrial kneader to verify its potentiality in the process optimization, verifying if, and how, the laboratory procedure is applicable in the food industry.

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