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The Rheological Properties of Semolina Doughs: Influence of the Relative Amount of Ingredients

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In the present study, the rheological properties of doughs, prepared by mixing semolina with water, yeast and salt, were investigated with different relative amounts of the ingredients. The rheological measurements were carried out by an Anton Paar MCR 102 rheometer, equipped with a plate-plate fixture. In more detail, frequency sweep tests were performed. Indeed, frequency sweep measurements showed to be informative about the force and extension of the gluten network that, in turn, demonstrated to depend on the relative amount of ingredients. The oscillatory experiments were analyzed by means of the "weak gel model", whose parameters are directly related to such physical properties. It was found that doughs obtained with different amounts of ingredients showed significant differences in the rheological responses. The addition of yeast led to a significant viscosity and force network decrease, whilst the presence of salt produced an improve of the three-dimensional gluten network characteristics and, consequently, to the machinability of the dough. The study aims at contributing to a more efficient controllability in the industrial production of flour and semolina dough based foods, and in particular to that of "pani carasau", a typical high quality and valuable Sardinian bread, since this process is high energy consuming (mainly in the baking step), in order to decrease the amount of off-specification products, and so making the processes more energy efficient and sustainable.

1. Introduction

Pasta and bread are among the most consumed foods in the world. The quality of these products mainly depends on the dough properties. In industrial production, the dough rheological characterization is very important, useful to have insights both on the structure of the material, which is linked to its technological properties, and on the so called "texture", which is strictly connected to the perceived properties of the final product (Menjivar, 1990). The ingredients kneading stage is crucial in the definition of the rheological properties of the dough because, besides allowing the mixing of the ingredients and the formation of a coherent mass, it promotes the hydration of gluten proteins and the consequent building of the so called three-dimensional network, as already shown in a previous work (Fanari et al., 2019b). Moreover, the interaction of the gluten proteins with the other components, such as the water-soluble fraction of flour, salt, yeast and other additives, is important for developing the viscoelastic behaviour of the mixed dough (Fanari et al., 2019a). There is a competition between the components to bind with water, which makes the relative quantity of ingredients in the dough a critical factor (Mani et al., 1992).

Salt is one of the four essential ingredients (together with flour, water and yeast) in every bread formula. In addition to its organoleptic contribution, salt plays a critical technological role throughout the bread-making process (mixing and dough formation, leavening, baking and storage) (Miller and Hoseney, 2008). Since gluten itself is hydrophobic, the salt role is very important for the distribution of water and the production of dough with the desired elasticity, which is a very important quality parameter (Bloksma, 1990). It is well known that salt increases the mixing resistance of doughs, improves extension and extensibility, decreases the stickiness, helps to stabilize the yeast fermentation rate, leads to a more attractive crust color, improves the bread texture, delays

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the bread staling, and inhibits the microbial growth during the bread storage (Chen et al., 2019). The formation of the gluten network is delayed in the presence of NaCl, and this fact is attributed to a reduction in the gluten hydration rate (McCann and Day, 2013). This phenomenon leads also to a modification in the gluten protein network microstructure, promoting the presence of elongated protein strands instead of less connected protein particles. This difference could be associated with the way in which gluten proteins are hydrated at the very early moments of mixing, when the presence of NaCl could reduce the surface charge of gluten proteins, namely its ability to interact with water molecules (Fanari et al., 2019a). However, the research on the effect of salt on bread has shown conflicting results. Some studies found a decrease in the storage and loss modules (G' and G") with an increase in the amount of added NaCl (Angioloni and Dalla Rosa, 2005), while others reported an increase in the storage modulus (G') when NaCl is added to the dough (Beck et al., 2012). Chen et al. (2019) reported that the mixing time increased from 2.75 min for the dough without salt, to 4.75 min for the dough with 2.4 wt. % (based on the wheat flour) of salt, stating that the addition salt influences strength, resistance, and mixing stability. Moreover, Lynch et al. (2009) reported that a reduction of the salt content from 1.2 to 0.6 or 0.3 wt. % (based on the dough total weight) did not significantly affect the rheological properties and the bread-making performance, but adding no salt at all, however, led to a significant reduction in the dough and bread quality, with a substantial decrease of G' module. Also Larsson (2002) observed a significant decrease for the elastic modulus G' in the same conditions.

Yeast is another main component of doughs, especially when productions at industrial level are considered. The yeast fermentation produces not only CO_2, which is a fundamental component in leavening and baking steps, but also other metabolites, like ethanol, succinic and acetic acid, and glycerol; these substances may affect the final product quality, the flavor attributes but also the rheological properties of the dough (Aslankoohi et al., 2015). All major yeast metabolites were found to produce a softening effect on unfermented doughs, whilst glycerol merely has a diluting effect; ethanol, succinic acid and glutathione fundamentally alter the structure of the gluten network (Meerts et al., 2018). Alvarez-Ramirez et al. (2019) reported that the yeast content affects the non-linear viscoelastic behaviour, increasing both G' and G", due to the yeast incorporation of polysaccharides and proteins, and to the three-dimensional network gassing. Despite the importance that fermentation and yeast have on the dough structure, the number of fundamental rheological studies dealing with fermented doughs is limited because of the difficulty to characterize a material which is constantly evolving over time.

The aim of the present study is the rheological characterization of doughs with different composition in terms of water, salt and yeast and, subsequently, to address an empirical description of their influence on the dough properties. The study is focused on a commercial durum wheat semolina and on the recipe which are currently used in the production of the typical Sardinian bread called "*pani carasau*".

2. Dough rheology and "weak gel model"

Dough presents a viscoelastic, non-linear behaviour, so for this material the stress is a function of both the applied strain and the strain rate (Faridi and Faubion, 2012). With this regard, several fundamental rheological tests are proposed in the literature. As reported by Dobraszczyk and Morgenstern (2003), the most common categories are: (i) small deformation dynamic shear oscillation; (ii) small and large deformation shear creep and stress relaxation; (iii) large deformation extensional measurements; (iv) flow viscosimetry. Dynamic oscillation measurements, and in particular the small amplitude oscillatory shear (SAOS) tests, are ideal to characterize the structural properties of viscoelastic materials (Morrison, 2001). These tests usually operate in the linear viscoelastic deformation regime with low strain values, up to 1 % (Amemiya and Menjivar, 1992). Frequency sweep measurements can give useful insights on the differences in the dough network characteristics among samples with different composition. The "weak gel model" (Gabriele et al., 2001) is able to represent the trend of the complex viscoelastic module of foods as a function of the strain frequency. This model is based on the hypothesis of a supramolecular structure, which is constituted by droplets, solid particles, fibers, macromolecules, etc. According to this theory, viscoelastic foods can be thought as gels, with an intermediate behaviour between liquids and solids, in which the internal superstructure is organized as a three-dimensional network by means of intermolecular weak interactions. As a consequence, the weak gel, under low stresses or strains, mainly behaves like a solid ("strong gel"), while for high strains the intermolecular interactions break, and the material flows like a liquid (Gabriele et al., 2006). This is the reason why foods, at low frequencies (0.1-100 Hz), can be assimilated to weak gels. The mathematical representation of the weak gel model is the following equation:

$$G^*(\omega) = \sqrt{G'(\omega)^2 + G''(\omega)^2} = A_F\ \omega^{1/z} \tag{1}$$

where G^* is the viscoelastic modulus, ω is the frequency, A_F is a model parameter which is related to the strength of the interactions among the flow units (i.e. the strength of the network structure), and z is a model parameter which is linked to the extension of the three-dimensional network (Gabriele et al., 2001). In the literature there are several examples of weak gel model applications to the characterization of doughs, for example in the study of the effect of pentosan (Migliori and Gabriele, 2010) or in the biscuit modeling (Baldino et al., 2014).

3. Materials and methods

The dough samples were prepared by using the following ingredients: a commercial semolina characterized by 71.0 wt. % of carbohydrates, 13.0 wt. % of proteins, 1.5 wt. % of fat; distilled water; commercial fresh brewer's yeast (*Saccharomyces cerevisiae*); commercial sea salt. The dough preparation was performed by using a 10 g capacity mixograph (National Manufacturing, Lincoln, NB). For the investigation of the salt influence, the tested samples were composed by 10 g of semolina, 5 g of distilled water and a variable quantity of salt: 0.5, 1.5 and 3 wt. % (based on the semolina weight). For the study of the yeast impact, instead, 10 g of semolina were mixed with 5 g of distilled water and with 0.5, 1.5 and 3 wt. % of yeast (based on the semolina weight). These amounts were chosen considering that the dough of "pani carasau" is nowadays commercially obtained with 50 wt. % of water, 1.5 wt. % of yeast and 1.5 wt. % of salt, all based on semolina. To clearly understand the impact of these components, also a sample obtained by mixing just semolina and water in the same amounts as before (blank sample) was tested. Each sample was mixed for a fixed time before starting the measurement, the times considered being 10, 20, and 40 min. So, the analysis was carried out on seven different samples (one blank, three with yeast addition and three with salt addition) and for each of them three kneading times were taken into account, for a total of 21 experimental conditions. This was done to compare the samples in a range of mixing time values and not only for a specific one in order to observe possible differences due to the different development of the dough structure. The rheological measurements were performed using an MCR 102 Anton-Paar rheometer (Anton Paar GmbH, Austria), with a parallel plate geometry, equipped with a 25 mm plate. A piece of dough, after kneading by the mixograph, was loaded on the rheometer, compressed to a gap of 2 mm and then left at rest for 15 min, to allow the material relaxation, as suggested by Phan-Thien and Safari-Ardi (2006). To prevent the evaporation and drying of the sample, a layer of silicon oil was applied to the edge of it. The measurement temperature in the rheometer was kept constant at 25°C using a heating system based on the Peltier technology. Frequency sweep tests were performed with frequency ranging from 0.1 to 100 $\mathrm{rad\cdot s^{-1}}$ with a constant strain of 0.1 % that was the estimated linear viscoelastic limit (LVE) according to preliminary amplitude sweep tests. Complex module data, obtained from these experiments, were modeled as a function of the frequency by means of the weak gel model, computing the values of the model parameters (A_F and z). Each one of the 21 experimental conditions was replicated three times, for a total of 63 runs, and for each parameter the average value was taken as the result.

4. Results

In Figure 1a the values of the loss and storage modules are reported for the samples with a relative amount of salt of 1.5 wt. % (based on semolina) mixed for 10 and 40 min. It is possible to observe that the trend of the logarithmic modules is quite linear with the logarithmic frequency in the range here considered. Regarding the samples with addition of yeast, in Figure 2a the modules for the samples with a relative amount of yeast of 1.5 wt. % (based on semolina), mixed for 10 min and 40 min, are shown. Also in this case the trend is linear in the considered frequency range, despite a small deviation from the linear trend at very low frequencies. The same behaviour was found for all the other samples that were not reported for the sake of brevity. Consequently, as it can be seen from the regression curves reported in Figures 1b and 2b, the weak gel model properly describes the phenomenon of the complex module changing as a function of frequency. So, through the regression operated by the weak gel model, the values of A_F and z parameters were computed. In Figure 3 It is possible to observe the values of these parameters as a function of the relative amount of salt, and in Figure 4 those for yeast.

In Figure 3 a slight decrease in A_F and z parameters can be noted, with just a few exceptions, when the salt concentration increases from 0 to 3 wt. % (based on semolina). This decreasing trend of both the weak gel parameters is aligned with the results reported by Belz et al. (2018) and with the decreasing of both G' and G" reported by Angioloni and Dalla Rosa (2005), but it is opposite to what found by Beck et al. (2012). These differences in the dough rheological behaviour as a function of the salt amount might be due to the use of different flour varieties (Belz et al., 2012). Moreover, looking at the parameters as a function of the mixing time, we can state that A_F, for both the dough made only by water and semolina and the dough with an amount of 3 wt. % (based on semolina) of salt, presents a minimum value for 20 min, while z shows a similar behaviour, but only in the first case. This fact could be linked to the over-kneading of the sample, which can lead to a partial decay of the three-dimensional network properties (Fanari et al., 2019b). For the relative amount of salt equal to 0.5 and 1.5 wt. % (based on semolina), the parameters do not show any minimum value as a function of the mixing time, but seem to continuously decrease or, in some cases, to stabilize to the constant value reached after 20 min of kneading.

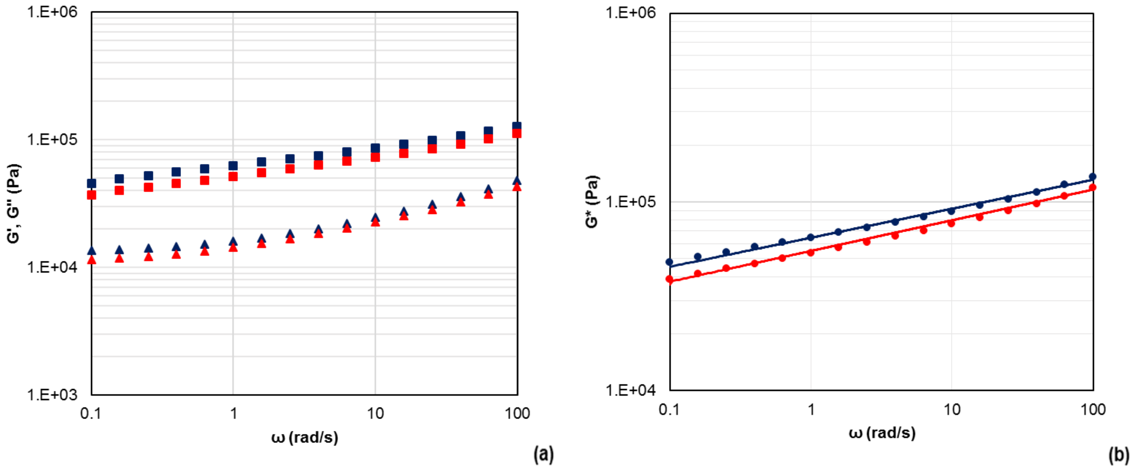

Figure 1: storage (squares) and loss (triangles) modules (a), complex modulus (points) and weak gel model curves (b) reported as a function of frequency; the blue color represents the sample with a relative amount of salt of 1.5 wt. % (based on semolina) mixed for 10 min, and the red color the same sample mixed for 40 min.

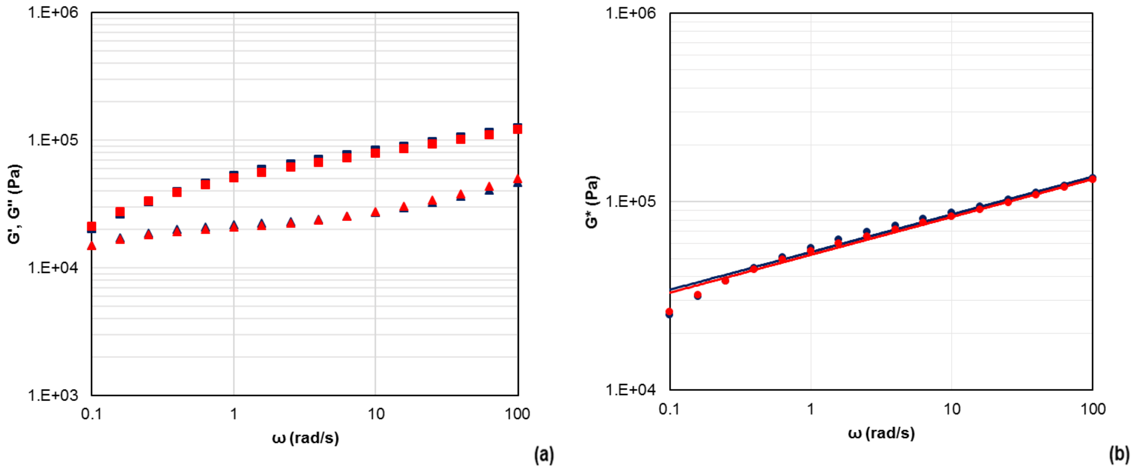

Figure 2: storage (squares) and loss (triangles) modules (a), complex modulus (points) and weak gel model curves (b) reported as a function of frequency; the blue color represents the sample with a relative amount of yeast of 1.5 wt. % (based on semolina) mixed for 10 min, and the red color the same sample mixed for 40 min.

Regarding the yeast addition, it is easy to observe, from Figure 4, that a higher added amount reduces both the model parameters, and this is due to the decreasing in the dough viscosity and of both G’ and G” modules, as reported also by Alvarez-Ramirez et al. (2019). The A_F parameter (and viscosity) reduction is already quite clear after 10 min of mixing. Moreover, also in this case, the trend over the mixing time is not the same for each sample. The addition of 0 and 3 wt. % (based on semolina) of yeast leads to a pronounced minimum for 20 min of kneading, whilst for intermediate amounts of yeast the stability of the network seems to be improved. Instead, the z parameter seems to be not significantly affected by the kneading time when no salt is added to the dough.

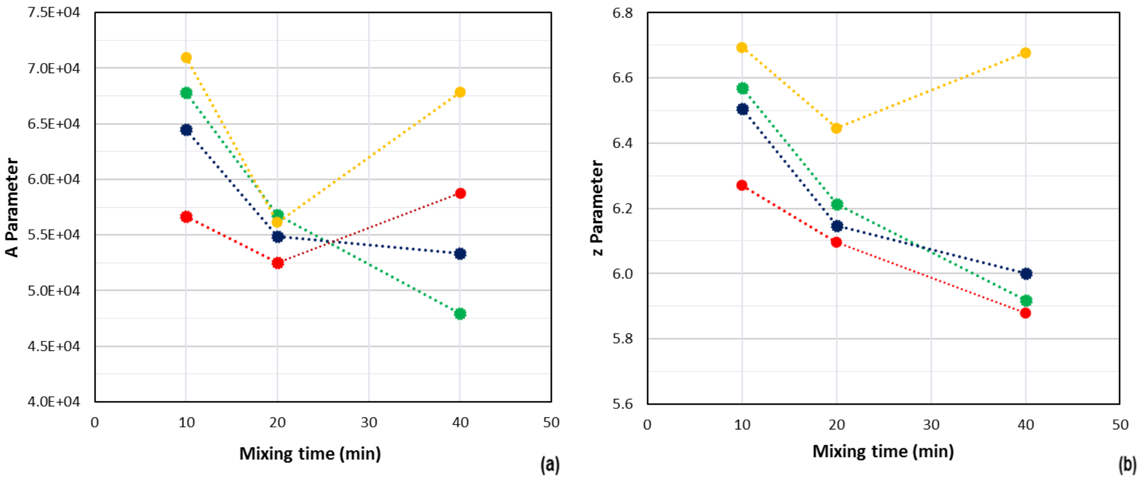

Figure 3: A_F (a) and z (b) parameters as a function of the salt content: 0 wt. % (•), 0.5 wt. % (•), 1.5 wt. % (•) and 3 wt. % (•) (percentages based on the semolina weight).

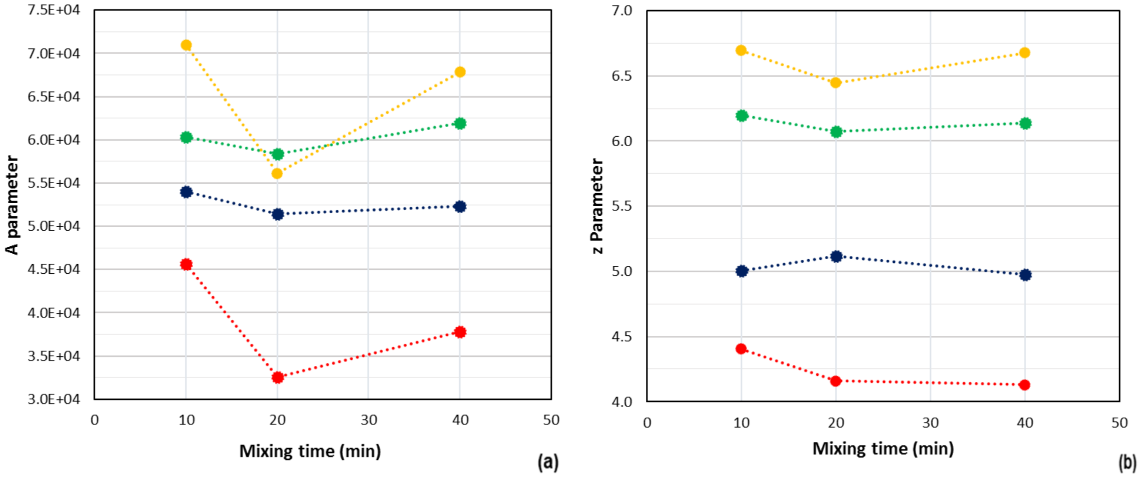

Figure 4: A_F (a) and z (b) parameters as a function of the yeast content: 0 wt. % (•), 0.5 wt. % (•), 1.5 wt. % (•) and 3 wt. % (•) (percentages based on the semolina weight).

5. Conclusions

The aim of this work was to find the impact of the amounts of salt and yeast on the rheological properties of the dough for the “pani carasau” production, particularly on the characteristics of the gluten three-dimensional network, which were quantified by means of the weak gel model. From the obtained results it is possible to say that both the salt and the yeast amounts affect the dough rheological characteristics, mainly reducing its viscosity.

The salt influence is positive when the addition is moderate (up to 1.5-2 wt. %, based on semolina), leading to an improving in the dough workability and elasticity, whilst it leads to a significant reduction of the dough viscosity for higher amounts. From these two different effects it can be supposed that the salt, when added in small amounts, helps the stabilization of the gluten network, improving its kneading performance and the dough machinability. On the contrary, for higher amounts of salt, there is a stronger competition between proteins and salt for binding free water molecules, so producing a decrease of the kneading resistance of the dough.

Regarding the yeast addition, instead, a stronger reduction in the model parameters, compared to the salt addition, is observable. Also in this case the addition of greater amounts seems to reduce the stability of the network, according to the observed kneading resistance.

For the future work development, it could be interesting to compare these results with those obtained by means of other characterization techniques, like thermal analysis or microscopic observation of the molecular structure, and to better study the interactions among the dough ingredients and their influence on the dough structure and properties, trying to correlate these phenomena with the observed rheological behaviour.

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