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Abstract

In Mediterranean countries, and in Sardinia in particular, durum wheat is traditionally used for bread production and modern cultivars have gradually replaced the use of old landraces due to the poor technological quality of the latter. However, recent escalation in customer demand for old varieties thanks to an appreciation of their nutritional properties, as well as ecological issues, has led to the need for technological improvements able to enhance the rheological performance of the old varieties to support their diffusion. The aim of this study was to assess whether the baking performance of an Old Italian wheat cultivar, Russello wheat, could be improved through the addition of different hydrocolloids (methylcellulose, guar, psyllium, xanthan and tara). The effects of two different concentrations (0.5% and 1%) of each hydrocolloid on the rheological properties, pasting, fermentation and microstructural properties of dough were assessed, and the results compared with those obtained using a modern durum wheat cultivar flour. Significant differences were found in the dough obtained with hydrocolloids. In particular, dough extensibility was increased with 1% psyllium or xanthan gum, whereas the gas retention coefficient was increased with all hydrocolloids. The pasting properties were modified via an increase in the final viscosity and setback value compared with control semolina (with the exception of methylcellulose); this resulted in a more homogeneous dough structure with a compact appearance and the absence of any deep interruptions in the gluten network as revealed by scanning electron microscopy.

Key words:
Old wheat cultivars; Baking properties; Hydrocolloids; Rheological properties; Scanning electron microscope.

1. Introduction

Bread is one of the most popular and most consumed foods in the world. Its principal ingredient is wheat flour, although other cereals can be also used, and it constitutes a major part of the average daily diet (Shewry, 2009). Bread is considered an important food for human nutrition due to its energetic value and content of proteins, vitamins, micronutrients, antioxidants and fibre (Valli, Taccari, Di Nunzio, Danesi, & Bordoni, 2018).

The characteristics of the bread depend on the quality of the flour and the bread-making procedures applied. A very voluminous, soft and elastic crumb, a uniform appearance and a relatively long shelf life are the features characterizing bread obtained with a refined flour. Flour quality is the key to obtaining an acceptable product and it is the quality and quantity of the flour's gluten proteins that determine this characteristic.

Bread flour is obtained worldwide by milling *Triticum aestivum* grains, but durum wheat semolina is also used to prepare flat breads in countries of the Middle East and pan bread in the Mediterranean area (Fadda, Angioloni, Piga, & Collar, 2010; Fadda, Santos, Piga, & Collar, 2010; Gallo et al., 2010). Renewed interest in the use of old varieties of durum wheat has gathered momentum over recent years due to their content of bioactive compounds that could be useful in producing health-promoting functional foods (Mefleh et al., 2019a; Shewry, 2018). Shewry and Hey (2015) compared data for 'ancient' durum with modern, detecting that 'ancient' wheat differ little from modern species in their contents and the latter may be lower in some components such as a dietary fibres and bioactive compounds. Dietary fibres are resistant to the digestion in the small intestine and they demonstrate their beneficial properties (Crittenden et al., 2002; De Santis et al., 2018). In fact, during digestion, the fibres reduce the absorption of glucose, cholesterol, fatty and bile acids. Furthermore, the soluble fibre fraction of old durum wheat varieties increases the probiotic bacteria activity, lowering concentration of phenols, pH, bile acids and raises the short chain fatty acids (Dinelli et al., 2009; Marotti et al., 2011). Another difference in the composition between old and modern grains is the density of micronutrients, with iron and zinc, being lower in modern species. Although it has been

suggested that the decrease in mineral density derives mainly from dilution yield (Murphy, Reeves, & Jones, 2008), the differences in density of micronutrients could be significant for some populations, since iron and zinc deficiencies affect about 2 billion people in the world (Fan et al., 2008). On the other hand, in the literature a clear understanding show that ancient and old wheat have higher contents of bioactive phytochemicals compounds (carotenoid, lutin, folates, B vitamins, tocols, terpenoids, phosphatidyl and lysophosphatidyl choline, sterols, phenolic acids, resorcinolic lipids), polar metabolites useful for the human diet, and dietary fibre components, than modern wheats (Shewry et al 2013; Shewry, Corol, Jones, Beale, & Ward, 2017; Shewry, 2018). Several trials described comparison of old wheats with modern durum wheats, measuring effects on values related to glycaemic index, cardiovascular disease, and irritable bowel syndrome (IBS) (Sofi et al., 2014). These studies reported the benefits of old grains varieties diet in important reduction in total cholesterol, LDL, blood glucose, insulin, protecting against oxidative stress, increasing serum potassium and magnesium levels, anti-inflammatory properties, reducing levels of pro inflammatory cytokines, Tumor Necrosis Factor (TNF)-alpha and vascular endothelial growth factor and interleukin-Ira (Sofi et al., 2013; Wittaker et al., 2015). This health promoting capacity has been demonstrated in different in vitro and animal studies carried out using extracts/lysates or compounds from old wheat (Jacobs, Meyer, Kushi & Folsom, 1998; Masisi, 2016). Pre modern wheat species have several prebiotic compounds as fermentable oligo-, di- and monosaccharides, and polyols (FODMAP). High FODMAP levels, which include the monosaccharide fructose, the disaccharide lactose, fructans, galactans, sorbitol and mannitol, have been suggested to worsen or probably even cause non-celiac wheat sensitivity (NCWS) and irritable bowel syndrome (IBS). NCWS belongs to the group of gluten-related disorders but, due to pathogenesis, it differs from celiac disease and wheat allergy (Leonard, Sapone, Catassi, & Fasano, 2017). The data of clinical trials suggested that lower FODMAP contents in old wheat varieties thanks to specific bread making step, are more suitable for individuals suffering from an irritable bowel syndrome (IBS), ensuring their absorption and

digestibility and they can alleviate IBS symptoms (Biesiekierski et al., 2013; Rao, Yu, & Fedewa, 2015; Ziegler et al, 2016).

Nonetheless, the poor technological properties of these cultivars with respect to modern wheat varieties pose severe problems for their use in modern bakery plants.

Dough preparation is the first and most critical step in the production of semolina products, which includes complex physical and biochemical modifications. During the transformation of the mixture of semolina and water into a dough, a three-dimensional gluten network is formed that creates a support structure involving hydrations, disulphide and ionic bonds, hydrogen bonds and hydrophobic connections (Cappelli et al., 2018). This gluten network embeds starch granules, fat and other dough components. The performance of the dough plays a key role in defining the quality of the final product. The physicochemical characteristics of the semolina influence the handling properties of the dough, its ability to leaven and the final bread attributes. Semolina from old durum wheat variety, when mixed with water and kneaded, results in a weak gluten network that has a poor capacity to release and retain gas, thus the obtained dough is of small volume and the resulting bread will be hard and have an uneven structure (Goesaert et al., 2005; Mefleh et al., 2019a).The gluten weakness of old durum wheat semolina is a major problem in bread-making, which is why flour additives should be considered able to improve the handling properties of dough, increase the quality of bread and prolong its shelf life. Genetically almost all old Italian durum wheat genotypes are characterized by their high molecular weight glutenin-20 and the γ-gliadin 42 type – related to the low molecular weight glutenin 1 considered a marker of weak gluten (Mefleh, Conte, Fadda, & Motzo, 2019b). In addition to commonly used additives, a class of compounds, the hydrocolloids, already extensively used in the food industry (Brandner, Becker, & Jekle, 2018; Li, Zhu, Madav, & Li, 2019a; Mikuš et al., 2013), are showing great promise due to their capacity to improve the dough rheology and quality of common bread (Collar, Conte, Fadda, & Piga, 2015; Ferrero, 2017; Gharaie, Azizi, Barzegar, & Aghagholizade, 2015; Rosell, Rojas, & De Barber, 2001; Sim, Noor Aziah, & Cheng, 2011; Wongklom, Cheamchaitrakun, & Punbusayakul, 2016) and are able to mimic the gluten properties of

gluten-free bread (Ahmed & Thomas, 2018; Linlaud, Puppo, & Ferrero, 2009). It stands to reason, therefore, that the hydrocolloids should be considered valid candidate bread improvers to be used in conjunction with old wheat semolina flours in the baking industry (Jafari, Koocheki, & Milani, 2018; Kohajdová & Karovičová, 2009). With this in mind, our goal was to evaluate the effects of different hydrocolloids at two concentrations on the rheological properties and quality of dough obtained using semolina from Russello, an Italian old durum wheat cultivar characterized by a weak and sticky gluten.

2. Materials and Methods

2.1. Materials and dough-making

Two semolina flours were used with different physicochemical characteristics (Table 1): one derived from a modern cultivar (MOD) and the other from an old genotype (OLD). The MOD was obtained from a national blend of Italian (80%) and Sardinian (20%) semolina (Molino Riu, Alghero, Italy), while the OLD was obtained by milling the Russello cultivar, a Sicilian old genotype commonly used to make pasta and semolina-based breads (Molini del Ponte, Castevetrano, Italy).

Five different hydrocolloids, namely: methylcellulose (MC), Guar gum (GG), Psyllium gum (PG), Xanthan gum (XG) and Tara gum (TG), were used separately in OLD samples at the following percentages: 0% (Control), 0.5% and 1% (Table 2). The moisture content of the commercial semolina flour and Russello semolina was determined following the appropriate ICC methods (ICC, 1976–1996). Analyses were performed in triplicate. The water absorption characteristics of the different formulations were obtained using a Brabender Farinograph (Model: 810104, Brabender, Duisburg, Germany). The parameters obtained from the Farinogram tests were: water absorption, dough development time (DDT) and stability time (time during which dough consistency was 500 B.U.).

Dough samples were prepared considering data obtained with the farinograph. Both semolina and hydrocolloids were premixed in dry conditions. The dough was optimally mixed at room temperature in a mixer (KitchenAid, Artisan, 5KSM150, USA) for 10 min at speed 2. Dough samples were stored

at room temperature, then divided into pieces of 100 g for rheological analysis and to investigate the effects of the hydrocolloids on the dough.

2.2. Rheological properties

2.2.1. Large deformation mechanical tests

Dough machinability was assessed as stickiness measurements using a TA-XT2 plus Texture Analyser (Stable Micro Systems Ltd., Godalming, UK) equipped with Texture Expert software for Windows. Dough stickiness was measured at room temperature using the SMS/Chen-Hoseney dough stickiness rig (A/DSC) and a 25 mm Perspex cylinder probe (P/25P) (Stable Micro-Systems, Surrey, UK). A millimetre of dough was extruded, relaxed for 30 seconds and placed under a 25 mm cylindrical probe (probe SMS P/25). Dough viscosity (i.e., resistance to extension) was measured as the maximum positive force (N).

Uniaxial extensibility was assessed using the SMS/Kieffer Dough and Gluten Extensibility Rig for the TA.XT2 plus Texture Analyser (Stable Micro Systems Ltd., Godalming, UK). Dough samples were prepared, in the absence of salt, through the addition of water according to farinographic water absorption (500 BU) to improve dough handling (i.e., to minimise its stickiness) without impairing the comparability of the different blends. After mixing, the dough samples were left to rest in a heating cabinet for 20 min at 25°C with 85% relative humidity (RH), then moulded by hand into balls. The dough was transferred into the moulding form and left to rest for 40 min at 25°C. The maximum peak force (resistance to extension) and the distance at sample rupture (extensibility) were recorded for ten dough strips per dough type.

2.2.2. Small deformation mechanical tests

Fundamental rheological measurements were performed by means of an oscillation test, using a dynamic shear rheometer (Anton Paar MCR 92, GmbH, Inc., Graz, Austria) fitted with a 50 mm plate (P50/P2). The dough sample was left to rest at room temperature for 10 min before analysis.

Approximately 2 g of the core of the dough was taken with a spatula. The sample was positioned between the plates for 2 min to relax and the upper plate was lowered against the sample to adjust the thickness to 2 mm. The edge of the sample was coated with a thin layer of paraffin oil to prevent the dough from drying out. Amplitude oscillatory strain experiments (0.01-10%) were made at 20°C and a 1 Hz frequency was selected to determine the dough's region of linear viscoelasticity. Frequency sweep measurements (0.1-10 Hz) were performed with a constant tension of γ 0.1% in the linear viscoelastic region. The storage modulus (G') and the loss modulus (G'') were determined.

2.2.3. Viscometric properties

The pasting properties of the different samples were detected using a Rapid Visco Analyser (RVA-4, Newport Scientific, Warriewood, Australia). Two concentrations of each hydrocolloid were combined with 3 g samples of semolina and 25 mL of distilled water, then mixed in the Analyser canister to prevent lumps. The RVA test was performed according to AACC method 76-21 (AACC, 2000). The pasting temperature, peak time (when peak viscosity occurred), peak viscosity (maximum hot paste viscosity), holding viscosity (minimum hot paste viscosity), breakdown (peak viscosity minus holding viscosity) and total setback (final viscosity minus holding viscosity) were calculated from the pasting curve using the software program Thermocline for Windows. Each measurement was performed in triplicate.

2.2.4. Fermentation properties of dough

The fermentation properties of dough containing the different hydrocolloids were tested using a F3 Rheofermentometer (Chopin, Paris, France). The samples, 315 g each, were placed into the test basket and incubated at 30°C for 3 hours. The dough development and gas release curve provided the following parameters: maximum dough height (Hm, mm); time at which dough reaches its maximum

height (T1); time of maximum gas formation (T'1); time at which gas starts to escape from the dough (Tx); and volume of carbon dioxide (mL) still retained in the dough at the end of the test (gas retention, %). The dough height at the terminate (Hm-h), gas retention and height loss were also determined and were considered a measure of dough stability during fermentation. The gas release curve was used to determine the retention coefficient R (CR) and is defined as the % ratio of the gas volume retained in the dough over the total gas volume produced during the assays. The test was repeated twice.

2.3. Microstructural analysis: scanning and transmission electron microscopy

For scanning electron microscopy (SEM), small portions of dough were cut and fixed overnight in 2.5% glutaraldehyde, then washed at 10 min intervals 3 times with 0.1 M phosphate-buffer (pH 7.4). Sections were then post-fixed in 1% OsO_4 for 1 h, washed at 10 min intervals 3 times with 0.1 M phosphate-buffer (pH 7.4) and 3 times with distilled water, dehydrated in graded ethyl alcohols for 30 min each, repeated 3 times. All samples were dried using the critical point method in a Polaron Jumbo (Quorum Technologies Ltd, Ringmer, East Sussex, England) apparatus. Sections were coated with gold in an Edwards S150A Sputter Coater unit (Manor Royal Crawley – West Sussex, England). The microstructure of dough was observed at 20 kV in a Zeiss DSM 962 conventional scanning electron microscope (Oberkochen, Germany).

2.4. Statistical analysis

Data from each experiment were subject to one-way analysis of variance (ANOVA) using Minitab® 17.1.0 software (Minitab, Inc.). The Fisher's least significant difference (LSD) test was applied to calculate the difference between each pair of means with a 95% confidence level (p-value < 0.05).

3. Results and discussion

3.1. Empirical rheological properties of dough

Stickiness is an important factor influencing the handleability of dough in the bakery industry. High stickiness values are not desirable because the dough will stick to the surfaces of the kneader. The opposite is similarly unfavourable, with low adhesiveness resulting in the dough failing to maintain its shape. The stickiness behaviours of control and hydrocolloid supplemented doughs are reported in Table 3. The stickiness value of dough made from OLD flour was significantly lower compared with that made with MOD, and, as expected, the addition of hydrocolloids increased the dough stickiness at both concentrations, except GG at 1% and PG at 0.5%. When TG at 1% was added to OLD flour, the stickiness of the resulting dough was the same as that for the MOD dough. Moreover, the use of MC and TG at 0.5% resulted in values of stickiness that exceeded that of MOD dough. Due to the presence of hydroxyl groups, hydrocolloids promote water absorption, which is responsible for greater stickiness. Dough supplemented with MC, an anionic hydrocolloid, showed a pseudoplastic behaviour due to the nature of the hydrocolloid that has an unusual thermal dependence on interfacial hydration. Moreover, MC is sensitive to the presence of salts and other solutes that compete for available hydration water (Ferrero, 2017; Grover, 1993). Several studies have suggested that MC and its derivates may interfere with gluten network formation by reducing cross-linking (Rosell & Foegeding, 2007). In our study, these changes correlated positively with the increase in stickiness, supposed the presence of MC promoted protein solubility.

The data provided by the Kieffer dough and gluten extensibility test confirm the poorer quality of OLD semolina with respect to MOD (Table 3). In this case, the addition of hydrocolloids in general did not promote the increment in the resistance to extension; rather the use of TG and XG at 0.5% decreased the extensibility of the dough, while PG at both percentages and XG at 1% resulted in a significant increase. Thus, the extensibility of the supplemented dough may be related, not only to the hydrocolloid concentration, but also to its structure and hydrophobicity. Moreover, a reduced resistance to extension (N) indicated a hardening of the mixture in the presence of hydrocolloids. The

rigid structure of XG (Glicksman, 1982) could be related to the reduction in gluten network cohesion. These changes in the dough behaviour are probably the result of interactions between the hydrocolloid and other dough components, especially the gluten network. Some authors (Linlaud et al.,2009; Ribotta, Ausar, Beltramo, & León, 2005) have reported a strengthening of dough following the addition of anionic hydrocolloids (for example, guar gum). They attributed this result to the formation of an anionic complex between the gum and gluten proteins, as well as the formation of hydrogen bonds. Our data seem to indicate that XG, an anionic hydrocolloid, does not affect dough stability, but brings about important changes to the textural attributes of the OLD dough. Therefore, the potential interaction of XG with the gluten network and the resulting change in rheological performance could be interpreted as the result of several factors: conformation, size of the polysaccharide chain and the ionic character. Furthermore, each change was influenced by the composition of the dough's matrix and water absorption capacity.

3.2. Dynamic rheological features

The storage modulus (G') and loss modulus (G'') of dough samples are reported in Fig. 1. In general, the addition of hydrocolloids resulted in a change in both G' and G''. However, despite the magnitude of both moduli, the G' values were higher than G" for all dough samples tested throughout the frequency range (0.1 to 10 Hz), thus indicating a stronger and less extensible dough, as well as more elastic interactions, which is typical of a solid, elastic-like performance. It has been suggested that hydrocolloids could establish electrostatic interactions with gluten, thereby increasing the elastic behaviour of the dough (Bárcenas, De la O-Keller, & Rosell, 2009; Li et al., 2019a; Ribotta et al., 2005). Several studies show that MC has an important influence on viscosity at low shear rates (Moreira, Chenlo, Silva, & Torres, 2007; Song & Zheng, 2007). A decrease in G' was detected following the addition of MC (1%), probably because the interaction between hydrocolloid and gluten had a negative effect on the three-dimensional gluten network.

3.3. Pasting profile

The influence of different hydrocolloids on the pasting properties of dough is shown in Fig. 2. The peak value reflects the maximum viscosity during the heating stage, when the starch granules begin to swell. The granules absorb and hold more water, reducing the effect of free water causing interference between starch granules – known as pasting – which represents the rapid increase in viscosity in this heating stage. Starch paste is a suspension that mainly consists of amylopectin in a continuous phase, made up of amylose and hydrocolloids. (Li et al., 2019a; Rosell & Foegeding, 2007). When starch granules swell even further, due to the addition of hydrocolloids, it is possible to observe a synergistic thickening, with a consequent increase in the viscosity of the starch paste. The pasting profile results revealed that OLD dough samples had lower pasting properties than MOD ones. Hydrocolloid addition, except in the case of MC, improved the pasting characteristics of OLD semolina flour, and XG and GG at 1% enabled samples to obtain values like those for MOD dough. Following peak viscosity, a breakdown in the starch granules occurred, especially when XG at 0.5% was added. The values at the end of the holding stage (trough) showed a decrease in viscosity with respect to the peak. Hydrocolloid-supplemented dough, except for MC addition at 0.5%, exhibited a significant increase in final viscosity with respect to OLD control dough. These gums compete with starch to absorb water during the starch gelatinization phase, resulting in starch that has difficulty gelatinizing (Correa, Ferrer, Añón, & Ferrero, 2014; Li, Yadav, & Li, 2019b; Li et al., 2019a). Setback, that is the degree of recrystallization of amylose after starch gelatinization, was significantly affected by all hydrocolloids at all percentages used compared with MOD control dough. In fact, all hydrocolloids increased the setback value, except MC at 0.5% and PG at 0.5%.

3.4. Fermentation behaviour of dough containing hydrocolloids

The dough fermentation properties as measured by the rheofermentometer are reported in Table 4. During fermentation, the gas produced by yeast activity diffuses into the dough and increases the number of air bubbles during mixing. The relation between gas production and retention is expressed

as the percentage of gas retained in the dough (Fois et al., 2012; Guarda, Rosell, Benedito, & Galotto, 2004; Liu, Mu, Sun, Zhang, & Chen, 2016). A lower value of (Hm-h)/Hm indicates greater pore space stability in the dough. The fermentation properties of the different dough samples were differently influenced by the hydrocolloids. Hm increased during fermentation following hydrocolloid supplementation, except for XG at 1%. It was possible to observe that MC, XG, TG at 1% and XG, at both percentages, increased the development of the dough height, recording significant values for T1 (when the dough distributes the max height).

Regarding gas behaviour, the time at which the gas started to escape the dough (Tx) was reduced in the hydrocolloid-supplemented dough, except for dough supplemented with MC at 0.5%, but the statistical significant ($p < 0.05$) reduction was only observed in the case of XG at both percentages. The addition of hydrocolloids did not significantly affect T'1. Furthermore, gas retention (Vr/Vt) increased significantly ($p < 0.05$) through the addition of hydrocolloids, except MC at 0.5%, suggesting that the right extensibility of the supplemented dough reinforced the gas cells that expand during the test, thus improving the gas retention capacity. This parameter is correlated to the dough's capacity to be stretched into thin films, and this property is associated with the quality of the gluten protein network (Li et al., 2019a; Rosell et al., 2001). These results support the use of hydrocolloids in dough with a weak gluten network, which has a poor capacity to leaven and retain gas.

3.5. Microstructural characteristics of dough

The microstructure of dough with and without hydrocolloids as revealed by SEM is shown in Fig. 3. This analysis provides more information helpful for understanding the interaction between hydrocolloids and gluten proteins. In the dough produced with OLD semolina (Fig. 3B), it was observed a continuous gluten film structure that wraps the two different types of starch granules (large A-type and the smaller B-type starch). Moreover, it can be noted the presence of gluten proteins forming a dense but discontinuous network able to retain starch granules. In contrast, as seen in Fig.

3A, the dough produced with MOD semolina not presented a disaggregated matrix, but exhibited a continuous gluten structure. The addition of MC to the dough, at both percentages, resulted in a more open and filamentous structure with well distinguished gluten strands. These samples showed a broken matrix with a non-continuous gluten film and a filamentous structure (Fig. 3C and 3D). The addition of XG, unlike MC, resulted in a more homogeneous structure (Fig. 3M and 3N), with a compact appearance and the absence of deep interruptions in the gluten network, even though the structure formed appeared more disordered than that of the OLD dough.

The presence of TG in the dough at 1% resulted in a compact gluten network, which incorporated the starch granules in a random manner such that the two types of granules were overlapping (Fig. 3L). The addition of GG and PG resulted in a structure with starch granules arranged in a film-like manner and the absence of any severe interruptions in the gluten network. The gluten matrix of GG- and PG-supplemented dough appeared like that of the OLD dough (Fig. 3E, 3F, 3G and 3H). Indeed, GG and PG seem to result in the best integrated gluten network. It can be noted how the addition of GG, an anionic linear hydrocolloid, resulted in the inclusion of starch granules. This is because GG can associate with gluten proteins through hydrogen bonds and this may also explain the noted change in the dough's structure as seen by SEM. Several studies have shown a good interaction between hydrocolloids and gluten proteins (Correa et al., 2014; Ferrero, 2017; Gao et al., 2017; Li et al., 2019a; Ribotta et al., 2005). The use of GG results in a disordered and less cross-linked protein structure at 1%, indeed some authors indicated a positive effect at percentage of use less than 1% (Linlaud et al., 2009; Maleki & Milani, 2013). This is due to the very small number of alpha helices and abundance of hydroxyl groups in GG's structure (Li et al, 2019a; Li et al, 2019b). This property favours the interaction of GG with the proteins of the gluten matrix through electrostatic interactions and hydrogen bonds (Ribotta, Pérez, León, & Añón, 2004; Ribotta et al., 2005; Zhou et al., 2014).

The other hydrocolloids work as fillers in the dough matrix, as in the case of MC, which showed a more disintegrated network and the absence of any continuous gluten film. Several authors have proposed that hydrocolloid competition with gluten proteins for water is another factor that affects

gluten development (Linlaud et al., 2009; Maleki & Milani, 2013; Ribotta et al., 2005). Some hydrocolloids may have a positive role in reinforcing the dough, whereas others may break the gluten network down, producing a less stable dough (Ferrero, 2017; Li, Yadav, & Li, 2019b; Rosell et al., 2001). The hydrocolloids competition with gluten proteins for water is an important element that influences the gluten development. Studies reported a less extensibility and a more resistance of the carboxymethyl and hydroxylpropilmethyl cellulose (Correa, Añón, & Pérez, 2010; Ferrero 2017; Linlaud et al., 2009; Tavakolipour & Kalbasi-Ashtari, 2006). Other hydrocolloids, such as GG and XG have been shown to support the gluten network (Correa et al., 2010; Linlaud et al., 2009; Ribotta et al., 2005). Our results confirm that it was possible to develop the gluten network in the presence of all the hydrocolloids studied.

The hydrocolloids also showed a strong capacity to bind starch via hydrogen bonding, causing a noticeable effect on the thermal properties of starch, except for MC-supplemented dough.

4. Conclusions

In the present work, we studied the behaviour and the rheological characteristics of dough made with Russello semolina supplemented with five different hydrocolloids at a concentration of either 0.5% or 1% and the possible interactions these supplements had with the gluten network. Water absorption was related to the type and the concentration of the hydrocolloid in the dough and whether a gluten network was developed or not. With respect to the MOD dough, the rheological characteristics of the OLD dough were improved by application of hydrocolloids, except for MC, which mainly improved the pasting profile and viscosity of the OLD dough.

All hydrocolloids gave excellent results in terms of the development and fermentation of the dough, especially when a long fermentation process is required.

The microstructural results confirmed that the hydrocolloids studied, except MC, possess a strong capacity to bind to starch via hydrogen bonding. These results show that the different structural and

composition characteristics of hydrocolloids influence the extent and the kind of interactions occurring among them and with the dough matrix. Furthermore, we show that the interaction of hydrocolloids with gluten proteins plays a key role in dough functional properties. The information herein obtained on the effect of different hydrocolloids could prove to be useful when improvements in the technological characteristics of dough are required for bread-making using flours obtained from old durum wheat varieties.

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References

AACC. (2000). *Approved methods of the American Association of Cereal Chemists*. Method 76–21 AACC.

Ahmed, J., & Thomas, L. (2018). Effect of xanthan and guar gum on the pasting, stickiness and extensional properties of brown wheat flour/β-glucan composite doughs. *LWT - Food Science and Technology*, *87*, 443–449. https://doi.org/10.1016/j.lwt.2017.09.017.

Bárcenas, M. E., De la O-Keller, J., & Rosell, C. M. (2009). Influence of different hydrocolloids on major wheat dough components (gluten and starch). *Journal of Food Engineering*, *94*(3–4), 241–247. https://doi:10.1016/j.jfoodeng.2009.03.012.

Biesiekierski, J. R., Peters, S. L., Newnham, E. D., Rosella, O., Muir, J. G., & Gibson, P. R. (2013). No effects of gluten in patients with self-reported non-celiac gluten sensitivity after dietary reduction of fermentable, poorly absorbed, short-chain carbohydrates. *Gastroenterology*, *145*(2), 320-328.e3. https://doi.org/10.1053/j.gastro.2013.04.051.

Brandner, S., Becker, T., & Jekle, M. (2018). Wheat dough imitating artificial dough system based on hydrocolloids and glass beads. *Journal of Food Engineering*, *223*, 144–151. https://doi.org/10.1016/j.jfoodeng.2017.12.014.

Cappelli, A., Cini, E., Guerrini, L., Masella, P., Angeloni, G., & Parenti, A. (2018). Predictive models of the rheological properties and optimal water content in doughs: An application to ancient grain flours with different degrees of refining. *Journal of Cereal Science*, *83*, 229–235. https://doi.org/10.1016/j.jcs.2018.09.006.

Collar, C., Conte, P., Fadda, C., & Piga, A., (2015). Gluten-free dough-making of specialty breads: significance of blended starches, flours and additives on dough behaviour. *Food Science and Technology International*. *21*(7), 523–536. https://doi.org/10.1177/1082013214552862.

Correa, M. J., Añón, M. C., Pérez, G. T., & Ferrero, C. (2010). Effect of modified celluloses on dough rheology and microstructure. *Food Research International*, *43*(3), 780–787. https://doi.org/10.1016/j.foodres.2009.11.016.

Correa, M. J., Ferrer, E., Añón, M. C., & Ferrero, C. (2014). Interaction of modified celluloses and pectins with gluten proteins. *Food Hydrocolloids*, *35*, 91–99. http://dx.doi.org/10.1016/j.foodhyd.2013.04.020.

Crittenden, R., Karppinen, S., Ojanen, S., Tenkanen, M., Fagerström, R., Mättö, J., Saarela, M., Mattila-SAndholm, T., & Poutanen, K. (2002). *In vitro* fermentation of cereal dietary fibre carbohydrates by probiotic and intestinal bacteria. Journal of the Science of Food and Agriculture, 82(8), 781–789. https://doi.org/10.1002/jsfa.1095.

De Santis, M. A., Kosik, O., Passmore, D., Flagella, Z., Shewry, P. R., & Lovegrove, A. (2018). Comparison of the dietary fibre composition of old and modern durum wheat (*Triticum turgidum* spp. *durum*) genotypes. *Food Chemistry*, *244*(June 2017), 304–310. https://doi.org/10.1016/j.foodchem.2017.09.143.

Dinelli, G., Carretero, A. S., Di Silvestro, R., Marotti, I., Fu, S., Benedettelli, S., Ghiselli, L., & Gutiérrez, A. F. (2009). Determination of phenolic compounds in modern and old varieties of durum wheat using liquid chromatography coupled with time-of-flight mass spectrometry. *Journal of Chromatography A, 1216*(43), 7229–7240. https://doi.org/10.1016/j.chroma.2009.08.041.

Fadda, C., Angioloni, A., Piga, A., & Collar, C. (2010). Impact of sourdough, yeast and gluten on small and large deformation rheological profiles of durum wheat bread doughs. *European Food Research and Technology, 231*(3), 431–440. http://doi:10.1094/CCHEM-87-3-0204.

Fadda, C., Santos, E. M., Piga, A., & Collar, C. (2010). Innovative traditional Italian durum wheat breads: Influence of yeast and gluten on performance of sourdough Moddizzosu breads. *Cereal Chemistry*, 87(3), 204–213. https://doi.org/10.1094/CCHEM-87-3-0204.

Fan, M. S., Zhao, F. J., Fairweather-Tait, S. J., Poulton, P. R., Dunham, S. J., & McGrath, S. P. (2008). Evidence of decreasing mineral density in wheat grain over the last 160 years. *Journal of Trace Elements in Medicine and Biology*, *22*(4), 315–324. https://doi.org/10.1016/j.jtemb.2008.07.002.

Ferrero, C. (2017). Hydrocolloids in wheat breadmaking: A concise review. *Food Hydrocolloids, 68*, 15–22. http://dx.doi.org/10.1016/j.foodhyd.2016.11.044.

Fois, S., Fadda, C., Tonelli, R., Sanna, M., Urgeghe, P.P., Roggio, T., & Catzeddu, P. (2012). Effects of the fermentation process on gas-cell size two-dimensional distribution and rheological characteristics of durum-wheat-based doughs. *Food Research International, 49*, 193–200. http://dx.doi.org/10.1016/j.foodres.2012.07.058.

Gallo, G., Bianco, M. L., Bognanni, R., Saimbene, G., Orlando, A., Grillo, O., Saccone, R., & Venora, G. (2009). Durum wheat bread: Old Sicilian varieties and improved ones. Conference paper at the *5th International Technical Symposium on Food Processing, Monitoring Technology in Bioprocesses and Food Quality Management*. Potsdam, Germany.

Gao, Z., Fang, Y., Cao, Y., Liao, H., Nishinari, K., & Phillips, G. O. (2017). Hydrocolloid-food component interactions. *Food Hydrocolloids*, *68*, 149–156. https://doi.org/10.1016/j.foodhyd.2016.08.042.

Gharaie, Z., Azizi, M. H., Barzegar, M., & Aghagholizade, R. (2015). Effects of hydrocolloids on the rheological characteristics of dough and the quality of bread made from frozen dough. *Journal of texture studies*, *46*(5), 365–373. http://doi:10.1111/jtxs.12136.

Glicksman, M. (1982). Food hydrocolloids. (1th ed.). CRC Publ, Boca Raton, Florida, (Volume 1).

Goesaert, H., Brijs, K., Veraverbeke, W. S., Courtin, C. M., Gebruers, K., & Delcour, J. A. (2005). Wheat flour constituents: how they impact bread quality, and how to impact their functionality. *Trends in Food Science & Technology*, *16*(1-3), 12–30. http://doi:10.1016/j.tifs.2004.02.011.

Grover, J. A. (1993). Methylcellulose and its derivatives. In R. L. Whistler, & J. N. Be Miller (Eds.), *Industrial gums* (pp. 475–504). San Diego, Academic Press.

Guarda, A., Rosell, C. M., Benedito, C., & Galotto, M. J. (2004). Different hydrocolloids as bread improvers and antistaling agents. *Food Hydrocolloids, 18*(2), 241–247. http://doi:10.1016/S0268-005X(03)00080-8.

ICC. (1976–1996). *ICC Standard Methods of the International Association for Cereal Chemistry*. Method 104–1, 105–2, 110–1, 115–1, 136, 162, 166. Vienna: The Association.

Jacobs, Jr., D. R., Meyer, K. A., Kushi, L. H., & Folsom, A. R. (1998). Whole-grain intake may reduce the risk of ischemic heart disease death in postmenopausal women: the Iowa Women's Health Study. *The American Journal of Clinical Nutrition, 68*(2), 248–257. http://doi:10.1093/ajcn/68.2.248.

Jafari, M., Koocheki, A., & Milani, E. (2018). Functional effects of xanthan gum on quality attributes and microstructure of extruded sorghum-wheat composite dough and bread. *LWT - Food Science and Technology*, *89*, 551–558. https://doi.org/10.1016/j.lwt.2017.11.031.

Kohajdová, Z., & Karovičová, J. (2009). Application of hydrocolloids as baking improvers. *Chemical Papers*, *63*(1), 26–38. https://doi.org/10.2478/s11696-008-0085-0.

Leonard, M. M., Sapone, A., Catassi, C., & Fasano, A. (2017). Celiac disease and nonceliac gluten sensitivity: A review. *JAMA - Journal of the American Medical Association*, *318*(7), 647–656. https://doi.org/10.1001/jama.2017.9730.

Li, J., Yadav, M.P., & Li, J. (2019a). Effect of different hydrocolloids on gluten proteins, starch and dough microstructure. *Journal of Cereal Science*, *87*, 85–90. https://doi.org/10.1016/j.jcs.2019.03.004.

Li, J., Zhu, Y., Yadav, M. P., & Li, J. (2019b). Effect of various hydrocolloids on the physical and fermentation properties of dough. *Food Chemistry*, *271*, 165–173. https://doi.org/10.1016/j.foodchem.2018.07.192.

Linlaud, N. E., Puppo, M. C., & Ferrero, C. (2009). Effect of hydrocolloids on water absorption of wheat flour and farinograph and textural characteristics of dough. *Cereal chemistry*, *86*(4), 376–382. https://doi.org/10.1094/CCHEM-86-4-0376.

Liu, X. L., Mu, T. H., Sun, H. N., Zhang, M., & Chen, J. W. (2016). Influence of potato flour on dough rheological properties and quality of steamed bread. *Journal of Integrative Agriculture*, *15*(11), 2666–2676. https://doi.org/10.1016/S2095-3119(16)61388-6.

Maleki, G., & Milani, J. M. (2013). Effect of guar gum, xanthan gum, CMC and HPMC on dough rheology and physical properties of Barbari bread. *Food Science and Technology Research*, *19*(3), 353–358. https://doi.org/10.3136/fstr.19.353.

Marotti, I., Bregola, V., Aloisio, I., Di Gioia, D., Bosi, S., Di Silvestro, R., Quinn, R., & Dinelli, G. (2012). Prebiotic effect of soluble fibres from modern and old durum-type wheat varieties on *Lactobacillus* and *Bifidobacterium* strains. *Journal of the Science of Food and Agriculture*, *92*(10), 2133–2140. https://doi.org/10.1002/jsfa.5597.

Masisi, K., Beta, T., & Moghadasian, M. H. (2016). Antioxidant properties of diverse cereal grains: A review on in vitro and in vivo studies. *Food Chemistry*, *196*, 90–97. https://doi.org/10.1016/j.foodchem.2015.09.021.

Mefleh, M., Conte, P., Fadda, C., Giunta, F., Piga, A., Hassoun, G., & Motzo, R. (2019a). From ancient to old and modern durum wheat varieties: interaction among cultivar traits, management, and technological quality. *Journal of the Science of Food and Agriculture*, *99*(5), 2059–2067. https://doi.org/10.1002/jsfa.9388.

Mefleh, M., Conte, P., Fadda, C., & Motzo, R. (2019b). From seed to bread: variation in quality in a set of old durum wheat cultivars, *Journal of the Science of Food and Agriculture*. https://doi.org/10.1002/jsfa.9745.

Mikuš, L., Kováčová, M., Dodok, L., Medveďová, A., Mikušová, L., & Šturdík, E. (2013). Effects of enzymes and hydrocolloids on physical, sensory, and shelf-life properties of wheat bread. *Chemical Papers*, *67*(3), 292–299. https://doi.org/10.2478/s11696-012-0286-4.

Moreira, R., Chenlo, F., Silva, C., & Torres, M. D. (2017). Rheological behaviour of aqueous methylcellulose systems: Effect of concentration, temperature and presence of tragacanth. *LWT - Food Science and Technology*, *84*, 764–770. https://doi.org/10.1016/j.lwt.2017.06.050.

Murphy, K. M., Reeves, P. G., & Jones, S. S. (2008). Relationship between yield and mineral nutrient concentrations in historical and modern spring wheat cultivars. *Euphytica*, *163*(3), 381–390. https://doi.org/10.1007/s10681-008-9681-x.

Rao, S. S. C., Yu, S., & Fedewa, A. (2015). Systematic review: Dietary fibre and FODMAP-restricted diet in the management of constipation and irritable bowel syndrome. *Alimentary Pharmacology and Therapeutics*, *41*(12), 1256–1270. https://doi.org/10.1111/apt.13167.

Ribotta, P. D., Ausar, S. F., Beltramo, D. M., & León, A. E. (2005). Interactions of hydrocolloids and sonicated-gluten proteins. *Food Hydrocolloids*, *19*(1), 93–99. https://doi.org/10.1016/j.foodhyd.2004.04.018.

Ribotta, P.D., Pérez, G. T., León, A. E., & Añón, M. C. (2004). Effect of emulsifier and guar gum on micro structural, rheological and baking performance of frozen bread dough. *Food Hydrocolloids*, *18*(2), 305–313. https://doi.org/10.1016/S0268-005X(03)00086-9.

Rosell, C. M., & Foegeding, A. E. (2007). Interaction of hydroxypropylmethylcellulose with gluten proteins: Small deformation properties during thermal treatment. *Food Hydrocolloids*, *21*, 1092–1100. https://doi.org/10.1016/j.foodhyd.2006.08.003.

Rosell, C. M., Rojas, J. A., De Barber, C. B. (2001). Influence of hydrocolloids on dough rheology and bread quality. *Food Hydrocolloids*, *15*(1), 75–81. https://doi.org/10.1016/S0268-005X(00)00054-0.

Shewry, P. R. (2009). Wheat. *Journal of Experimental Botany*, *60*(6), 1537–1553. https://doi.org/10.1093/jxb/erp058.

Shewry, P. R. (2018). Do ancient types of wheat have health benefits compared with modern bread wheat? *Journal of Cereal Science, 79*, 469–476. https://doi.org/10.1016/j.jcs.2017.11.010.

Shewry, P. R., Corol, D. I., Jones, H. D., Beale, M. H., & Ward, J. L. (2017). Defining genetic and chemical diversity in wheat grain by 1H-NMR spectroscopy of polar metabolites. *Molecular Nutrition and Food Research*, *61*(7), 1–9. https://doi.org/10.1002/mnfr.201600807.

Shewry, P. R., Hawkesford, M. J., Piironen, V., Lampi, A. M., Gebruers, K., Boros, D., Andersson, A. A. M., Åman, P., Rakszegi, M., Bedo, Z., Ward, J. L. (2013). Natural variation in grain composition of wheat and related cereals. *Journal of Agricultural and Food Chemistry*, *61*(35), 8295–8303. https://doi.org/10.1021/jf3054092.

Shewry, P. R., & Hey, S. (2015). Do “ancient” wheat species differ from modern bread wheat in their contents of bioactive components? *Journal of Cereal Science*, *65*, 236–243. https://doi.org/10.1016/j.jcs.2015.07.014.

Sim, S. Y., Noor Aziah, A. A., & Cheng, L. H. (2011). Characteristics of wheat dough and Chinese steamed bread added with sodium alginates or konjac glucomannan. *Food Hydrocolloids*, *25*(5), 951–957. https://doi.org/10.1016/j.foodhyd.2010.09.009.

Sofi, F., Whittaker, A., Cesari, F., Gori, A. M., Fiorillo, C., Becatti, M., Marotti, I., Dinelli, G., Casini, A., Abbate, R., Gensini, G. F., & Benedettelli, S. (2013). Characterization of Khorasan wheat (Kamut) and impact of a replacement diet on cardiovascular risk factors: Cross-over dietary intervention study. *European Journal of Clinical Nutrition*, *67*(2), 190–195. https://doi.org/10.1038/ejcn.2012.206.

Sofi, F., Whittaker, A., Gori, A. M., Cesari, F., Surrenti, E., Abbate, R., Gensini, G. F., Benedettelli, S., & Casini, A. (2014). Effect of *Triticum turgidum* subsp. *turanicum* wheat on irritable bowel syndrome: A double-blinded randomised dietary intervention trial. *British Journal of Nutrition*, *111*(11), 1992–1999. https://doi.org/10.1017/S000711451400018X.

Song, Y., & Zheng, Q. (2007). Dynamic rheological properties of wheat flour dough and proteins. *Trends in Food Science and Technology*, *18*(3), 132–138. https://doi.org/10.1016/j.tifs.2006.11.003.

Tavakolipour, H., & Kalbasi-ashtari, A. (2006). Influence of gums on dough properties and flat bread quality of two persian wheat varieties. *Journal of Food Process Engineering*, *30*, 74-87. https://doi.org/10.1111/j.1745-4530.2007.00090.x.

Valli, V., Taccari, A., Di Nunzio, M., Danesi, F., Bordoni, A. (2018). Health benefits of ancient grains. Comparison among bread made with ancient, heritage and modern grain flours in human cultured cells. *Food Research International*, *107*(February), 206–215. https://doi.org/10.1016/j.foodres.2018.02.032.

Whittaker, A., Sofi, F., Luisi, M. L. E., Rafanelli, E., Fiorillo, C., Becatti, M., Abbate, R., Casini, A., Gian Franco Gensini, G. F., & Benedettelli, S. (2015). An organic khorasan wheat-based replacement diet improves risk profile of patients with acute coronary syndrome: A randomized crossover trial. *Nutrients*, *7*(5), 3401–3415. https://doi.org/10.3390/nu7053401.

Wongklom, P., Chueamchaitrakun, P., & Punbusayakul, N. (2016). Effect of xanthan gum/CMC on bread quality made from Hom Nil rice flour. *International Food Research Journal, 23(5),* 2300–2305.

Ziegler, J. U., Steiner, D., Longin, C. F. H., Würschum, T., Schweiggert, R. M., & Carle, R. (2016). Wheat and the irritable bowel syndrome - FODMAP levels of modern and ancient species and their retention during bread making. *Journal of Functional Foods, 25,* 257–266. https://doi.org/10.1016/j.jff.2016.05.019.

Zhou, Y., Zhao, D., Foster, T. J., Liu, Y., Wang, Y., & Nirasawa, S., et al. (2014). Konjac glucomannan-induced changes in thiol/disulphide exchange and gluten conformation upon dough mixing. *Food Chemistry*, *143*, 163–169. https://doi.org/https://doi.org/10.1016/j.foodchem.2013.07.088.

Figure legends

Fig. 1. Dynamic rheological parameters (G' and G'') of dough as a function of frequency for MOD and OLD control doughs (A) and with hydrocolloids: MC, methylcellulose (B); GG, Guar gum (C); PG, Psyllium gum (D); TG, Tara gum (E); XG, Xanthan gum (F).

Fig. 2. Effect of different hydrocolloids on pasting properties, peak viscosity (peak); holding strength (trough); the difference between peak viscosity and holding strength (breakdown); final viscosity and the different between final viscosity and holding strength (setback). Error bands represent the standard error. The same group of bars with different letters are significantly different ($p < 0.05$).

Fig. 3. Effect of different hydrocolloids at different use rates on the microstructure of dough by scanning electron microscopy: A) Control MOD; B) Control OLD; C) MC 0.5%; D) MC 1%; E) GG 0.5%; F) GG 1%; G) PG 0.5%; H) PG 1%; I) TG 0.5%; L) TG 1%; M) XG 0.5%; N) XG 1%. Gluten film structure wraps the two different types of starch granules, A-type (white arrow) and B-type (black arrow).

Table 1

Some chemical and physical characteristics of Semolina deriving from modern cultivar (MOD) and from *Russello* cultivar (OLD).

Characteristic	**Semolina MOD**	**Semolina OLD**
Chemical composition (%)		
Moisture content	12.3	12.5
Ash	0.88	1.09
Alveograph parameters		
P	108	26
L	39.5	61
G	14	17.4
W	170	42
P/L	2.73	0.43
Farinograph parameters		
Water absorption (%)	54.5	50.5
Development time (min)	02.05	04.9
Stability (min)	18.10	06.8
Colour		
L	66.75	64.52
a	-2.15	-1.21
b	19.99	18.64

Table 2

Chemical structures and physical properties of hydrocolloids used for blends.

Hydrocolloid	Producer	Chemical structure
Methylcellulose (MC)	Sigma-Aldrich, St. Louis, USA	(1,4)-β -D-glucan compound formed by methylating cellulose through exposure to NaOH/CH_3Cl. It derives from a 1,4-β-D-glucan
Guar gum (GG)	Chimab, Campodarsego, Italy	(1,4)-β-linked mannose residues to which galactose residues are 1,6-linked at second mannose, forming short side-branches
Psyllium gum (PG)	Chimab, Campodarsego, Italy	(1,4)-linked D-xylopyranosyl residues, some carrying single xylopyranosyl side chains at position 2, others bearing, at position 3, trisaccharide branches having the sequence 1-Araf- (1,3)-1-Araf.
Tara gum (TG)	Aglumix®01, Silvateam Food Ingredients S.r.l., Bergamo, Italy	(1,4)-β-D-mannopyranose units attached by (1-6) linkages with α-D-galactopyranose units
Xanthan gum (XG)	Chimab, Campodarsego, Italy	β-D-glucose units linked at the 1 and 4 positions

Table 3

Effect of hydrocolloids on stickiness and extensibility of doughs.

Sample	Hydrocolloid (%)	Stickiness (N)	Resistance to extension (N)
MOD	0.0	0.40 ± 0.01^{c}	0.23 ± 0.01^{a}
OLD	0.0	0.28 ± 0.01^{f}	0.12 ± 0.00^{d}
MC	0.5	0.58 ± 0.03^{a}	0.10 ± 0.03^{e}
MC	1	0.37 ± 0.01^{d}	0.12 ± 0.01^{d}
GG	0.5	0.36 ± 0.02^{de}	0.12 ± 0.04^{cd}
GG	1	0.29 ± 0.01^{f}	0.13 ± 0.01^{cd}
PG	0.5	0.29 ± 0.01^{f}	0.16 ± 0.01^{b}
PG	1	0.36 ± 0.01^{e}	0.17 ± 0.01^{b}
TG	0.5	0.46 ± 0.01^{b}	0.09 ± 0.01^{e}
TG	1	0.40 ± 0.01^{c}	0.09 ± 0.01^{e}
XG	0.5	0.35 ± 0.01^{e}	0.09 ± 0.00^{e}
XG	1	0.35 ± 0.02^{e}	0.14 ± 0.01^{c}

Results are expressed as force (N) means ± standard deviation (n =6). In the last column the data of the dough resistance to extension (N) are represented as Kieffer means ± standard deviation (n =6). Value in the column followed grouping information and with the same letter do not differ significantly from each other according to Fisher LSD test ($p < 0.05$) and values having different lower case letters (a, b, c, d, e…) within each column are significantly different at $p < 0.05$.

Table 4

Effect of percentage (0.0-0.5-1%) of five hydrocolloids on dough by rheofermentometer.

	Dough development*			Gas behaviour**		
Sample	Hm (mm)	(Hm-h)/Hm (%)	T1 (h)	Tx (h)	T'1 (h)	(CR) Vr/Vt: (%)
0%						
MOD	51.65±0.05 [b]	15.05±2.15 [d]	02.07.30±00.30.00[a]	01.15.45±00.02.15[a]	00.51.45±00.02.15[a]	87.10±0.10 [b]
OLD	42.90±0.80 [e]	14.08±2.10 [d]	01.29.15±00.04.30[c]	01.24.45±00.08.15[a]	01.09.00±00.01.30[a]	93.60±0.40 [b]
0.5%						
MC	44.35±0.05 [d]	17.95±8.85 [d]	01.24.45±00.00.45[c]	01.26.15±00.03.45[a]	01.15.00±00.00.00[a]	93.80±0.30 [b]
GG	50.35±1.25 [c]	30.40±1.8 [b]	01.30.45±00.03.45[c]	01.18.45±00.03.45[a]	01.00.00±00.01.30[a]	95.60±0.40 [a]
PG	50.90±0.7 [c]	25.25±5.65 [c]	01.39.45±00.00.45[bc]	01.21.00±00.03.00[a]	01.05.15±00.00.45[a]	94.90±0.00 [a]
TG	50.85±0.25 [c]	30.65±0.95 [b]	01.34.30±00.04.30[c]	01.22.30±00.03.00[a]	01.06.00±00.01.30[a]	95.15±0.35 [a]
XG	44.50±0.50 [d]	08.60±1.80 [e]	01.44.15±00.12.45[b]	01.08.15±00.02.15[b]	01.03.45±00.02.15[a]	94.70±0.30 [a]
1%						
MC	53.4±0.70[a]	31.50±0.80 [b]	01.45.00±00.07.30[b]	01.24.45±00.05.15[a]	01.03.00±00.04.30[a]	95.75±0.45 [a]
GG	51.55±0.55[b]	32.55±1.65 [a]	01.34.30±00.04.30[c]	01.21.00±00.00.00[a]	01.00.00±00.01.30[a]	96.35±0.05 [a]
PG	47.95±0.70 [bc]	23.05±0.65 [c]	01.26.15±00.02.15[c]	01.15.00±00.03.00[a]	01.03.45±00.00.45[a]	94.4±0.010 [a]
TG	50.70±0.30 [c]	35.95±1.65 [a]	01.43.30±00.03.00[b]	01.24.45±00.02.15[a]	01.07.30±00.01.30[a]	95.80±0.20 [a]
XG	42.15±1.05 [e]	12.25±3.25 [d]	01.47.15±00.00.45[b]	01.03.00±00.00.00[b]	01.00.00±00.03.00[a]	94.20±0.40 [a]

Hm, maximum dough development height; (Hm-h)/Hm, drop in dough height at the end of 3 h; T1, time at which dough spreads the maximum height. Gas behaviour, Tx, time at gas starts to escape from the dough, T'1, time of maximum gas formation; (CR) Vr/Vt, percentage of the gas withheld in the dough at the end of 3 h. Each value represents the mean ± standard deviation (n=3) and values having different lower case letters (a, b, c, d, e, f … …) within each column are significantly different at $p < 0.05$.

Figure 1

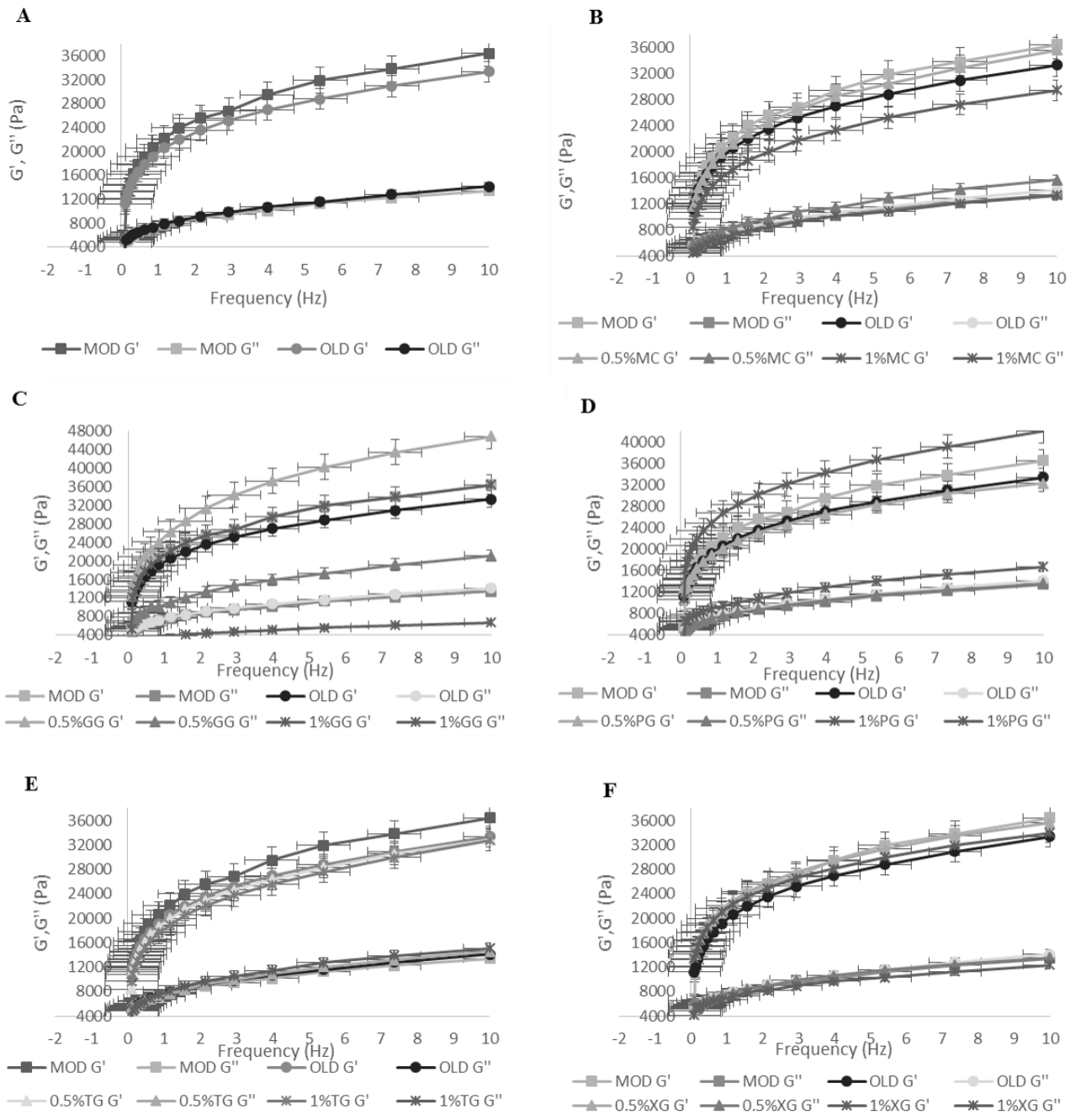
A
G', G'' (Pa)
Frequency (Hz)
MOD G'
MOD G''
OLD G'
OLD G''
B
G',G'' (Pa)
Frequency (Hz)
MOD G'
MOD G''
OLD G'
OLD G''
0.5%MC G'
0.5%MC G''
1%MC G'
1%MC G''
C
G',G'' (Pa)
Frequency (Hz)
MOD G'
MOD G''
OLD G'
OLD G''
0.5%GG G'
0.5%GG G''
1%GG G'
1%GG G''
D
G',G'' (Pa)
Frequency (Hz)
MOD G'
MOD G''
OLD G'
OLD G''
0.5%PG G'
0.5%PG G''
1%PG G'
1%PG G''
E
G',G'' (Pa)
Frequency (Hz)
MOD G'
MOD G''
OLD G'
OLD G''
0.5%TG G'
0.5%TG G''
1%TG G'
1%TG G''
F
G',G'' (Pa)
Frequency (Hz)
MOD G'
MOD G''
OLD G'
OLD G''
0.5%XG G'
0.5%XG G''
1%XG G'
1%XG G''

Figure 2

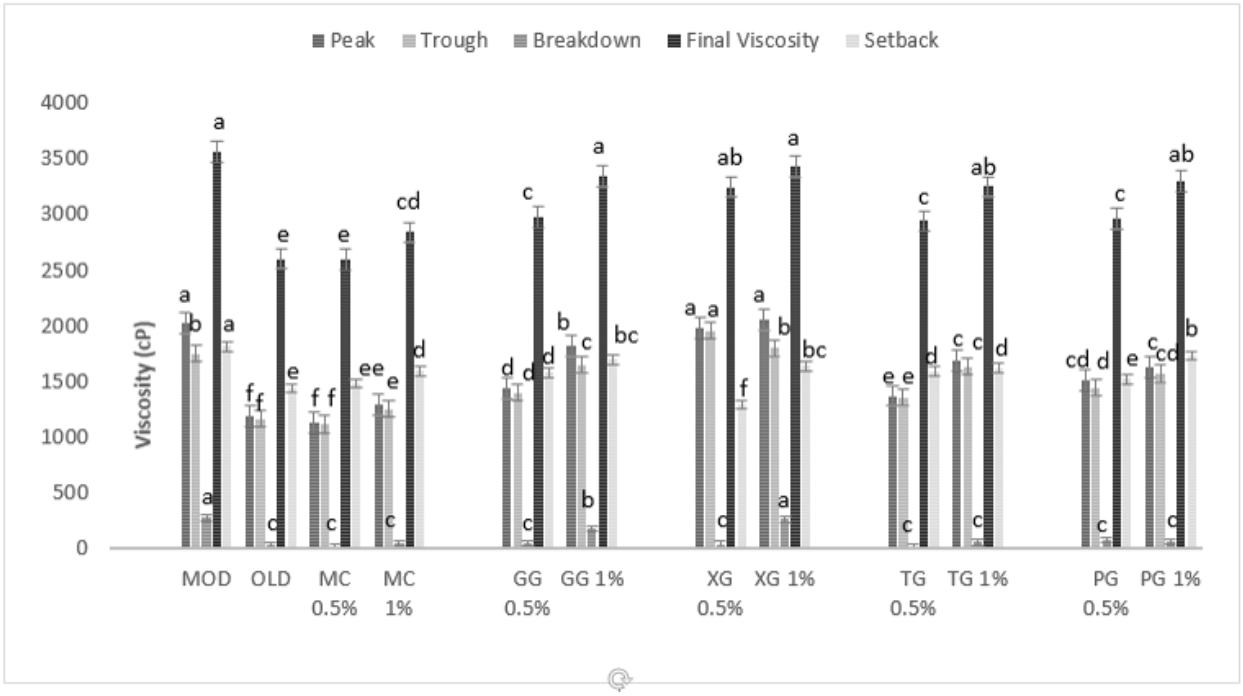
Peak
Trough
Breakdown
Final Viscosity
Setback
Viscosity (cP)
4000
3500
3000
2500
2000
1500
1000
500
0
MOD
OLD
MC 0.5%
MC 1%
GG 0.5%
GG 1%
XG 0.5%
XG 1%
TG 0.5%
TG 1%
PG 0.5%
PG 1%

Figure 3