Quality Assurance and Safety of Crops & Foods, 2019; 11 (7): 659-667
SPECIAL ISSUE: *Scientific trends of global food laws and regulations*

Thermo-mechanical behaviour of dough and bread making properties of soryz flour

A. Culetu, D.E. Duta*, G. Mohan and E. Iorga

National Institute of Research and Development for Food Bioresources, IBA Bucharest, Dinu Vintila 6, 021102 Bucharest, Romania; denisa.duta@bioresurse.ro

Received: 1 December 2018 / Accepted: 26 February 2019

RESEARCH ARTICLE

Abstract

Soryz (*Sorghum oryzoidum*) is a relatively new gluten-free cereal of hybrid origin from sorghum with potential in developing gluten-free products. The rheological behaviour of soryz in terms of thermo-mechanical properties assessed by Mixolab system was studied in comparison with other gluten-free sources from cereals (rice, oat, teff), pseudo-cereal (quinoa) and legume (soy). Soryz showed an atypical Mixolab curve with very low consistency until the gelatinisation temperature was reached. Soryz presented weaker protein network, lower water absorption and stability than other flours. Whole oat was characterised by the strongest protein network. Soy and whole oat flours had the highest water absorption, development time and improved stability as compared to the other samples. A positive correlation was found between protein weakening and dough stability (r=0.88; P<0.05). Soryz flour was characterised by higher starch swelling and, consequently, starch retrogradation also increased with increasing starch gelatinisation. A higher starch content was correlated with higher gelatinisation (r=0.76; P>0.05). A negative correlation was found between starch gelatinisation and protein content (r=-0.66; P>0.05) as well as lipid content (r=-0.77; P>0.05) of the gluten-free flours. The behaviour of soryz flour during mixing and heating with the help of Mixolab brings useful information in the development of gluten-free bakery products. Bread formulations on soryz flour as well as soy-soryz blends (5 and 10% soy flour addition) were tested for improving bread nutritional value. Addition of soy flour in soryz bread formulations, decreased the bread volume, porosity and lightness as well as increased hardness in comparison to soryz bread control.

Keywords: soryz, gluten-free dough, mixing, rheological properties, bread

1. Introduction

People who present gluten intolerance, gluten sensitivity or wheat allergy have to adopt a gluten-free diet which imposes a strict control of consumed foods for the gluten content. The main source of digestive problems is prolamins in wheat, rye and barley (Capriles and Arêas, 2014).

For developing new and diversified gluten-free baked products, different types of cereals were studied for their potential applicability in bread making: rice (Lazaridou *et al.*, 2007), sorghum and maize (Schober and Bean, 2008), buckwheat, amaranth, quinoa (Schoenlechner *et al.*, 2008; Turkut *et al.*, 2016), teff (Marti *et al.*, 2017), potato, cassava, tapioca starches (Gobbetti *et al.*, 2018), chestnut flour (Demirkesen *et al.*, 2010), chickpea flour (Kahraman *et al.*, 2018), defatted marama bean flour (Nyembwe *et al.*, 2018), soy flour (Moore *et al.*, 2008). Different technological approaches were tested to obtain baked products with good sensory qualities as similar as possible with wheat based bread: the use of enzymes, hydrocolloids, emulsifiers, sourdoughs (Gobbetti *et al.*, 2018).

Raw materials without gluten develop doughs with altered rheological properties and baked product with poor quality because of the lack of proteins which form the gluten network responsible for holding the gas produced during the fermentation. The effect of fibre rich flours on modifying the rheological properties of doughs based on rice was studied by researchers (Demirkesen *et al.*, 2010) who have shown that the addition of chestnut flour to rice flour determined the increase of the yield stress values and apparent viscosity values. Capriles and Arêas (2014) studied the effects of quinoa and buckwheat flours incorporated into rice flour and potato starch mixtures by rheological measurements of bread batters using a DHR3 rheometer. Due to the higher soluble fibre fraction, quinoa flour significantly influenced the viscosity and the water absorption capacity of batter increased more in case of quinoa flour than for buckwheat flour. Monthe *et al.* (2019) studied a mixture of fermented cassava – sweet potato – sorghum flours with xanthan gum as gluten substitute for gluten-free bread preparation. Fermented doughs were analysed for their rheological behaviour using a Physica Rheometer equipped with plan-plan parallel geometry with sanded surface probe to prevent slippage.

Among different rheological techniques, Mixolab has been used in many studies for analysing the appropriateness of non-gluten ingredients for the production of quality gluten-free bread. Mixolab is used to measure the rheological properties of dough subjected to dual stress of mixing and temperatures changes. The technique is able to characterise the thermo-mechanical properties of gluten-free matrixes (Rosell, 2013). The Mixolab is a complete tool for analysing dough behaviour, which depends on composition, ingredient quality and interactions. Data measured by the Mixolab device are strongly correlated with those determined with the Farinograph and Rapid Visco Analyser (Dubat, 2013).

The potential of defatted marama flour-cassava starch composites to produce functional gluten-free bread-type dough was studied using Mixolab (Nyembwe *et al.*, 2018). Alternative cereals (rice, corn), pseudo-cereals (buckwheat, amaranth) and legumes (soybean) were assessed by Mixolab (Hadnađev *et al.*, 2011) for their rheological properties. The results demonstrated that rice and buckwheat flours had similar water absorptions, stabilities and degrees of mechanical weakening as wheat flour. This conclusion is very useful for producing gluten-free breads with good quality. Mixolab profiles of some gluten-free ingredients: different types of flour (soy flour, amaranth flour, rice flour, buckwheat flour, wholegrain buckwheat flour), starch (maize starch, potato starch) and the most commonly used hydrocolloids gums – xanthan and guar gum were examined by Torbica and colleagues (2008). They found the Mixolab method of analysis very useful to predict the properties of raw ingredients in gluten-free doughs and not time consuming. Huang *et al.* (2010) studied the effects of addition of transglutaminase on the rheological and Mixolab thermomechanical characteristics of oat dough and could observe the decrease in water absorption when the level of transglutaminase was increased.

Soryz (*Sorghum oryzoidum*) is a relatively new gluten-free cereal of hybrid origin from sorghum (obtained in Republic of Moldova) with great potential for use in human nutrition. The aim of this study was twofold: first, to test the thermo-mechanical behaviour of the soryz in comparison to other gluten-free flours from different sources (i.e. rice, oat, quinoa, teff) as well as wheat and soy flours using the Mixolab system and, second, to test the possibility of improving the thermo-mechanical and bread making properties of soryz flour by soy flour addition.

2. Materials and methods

Materials

The following flours labelled as gluten-free were purchased from local market: whole rice (origin: Ukraine), teff (origin: Spain) and quinoa (origin: Peru). Wholemeal oat flour and soryz flour were obtained from PrimaVera Naturkorn (Mühldorf am Inn, Germany) and Andigor SRL (Chisinau, Republic of Moldova), respectively. Soy and wheat flours were from Romania.

For bread formulations, commercially available sugar, salt, oil and baking yeast were used. Carboxymethylcellulose and maize starch were purchased from Akzo Nobel (Arnhem, the Netherlands) and Roquette (Lestrem, France), respectively.

Gluten determination

Gluten content was determined by direct sandwich Enzyme-Linked Immunosorbent Assay (ELISA method) using Ridascreen® Gliadin Kit from R-Biopharm AG (Darmstadt, Germany).

Compositional analysis

The characteristics of the gluten-free flours were determined according to AOAC (2005) methods. Samples were analysed for moisture (AOAC 925.10), protein by Kjeldahl (AOAC 920.87), fat by Soxhlet (AOAC 945.38), ash by gravimetric (AOAC 923.03), dietary fibre and starch content by enzymatic method using assay kits K-TDFR 'Total dietary fibre' (AOAC 991.43) and K-TSTA 'Total starch' (AOAC 996.11) obtained from Megazyme International Ltd. (Bray, Ireland).

Thermo-mechanical properties

The rheological behaviour of gluten-free flours was investigated by using a Mixolab analyser (Chopin Technologies, Villeneuve-la-Garenne, France) with the modified 'Chopin+' protocol (ICC No. 173, 2006; Torbica *et al.*, 2010). The Mixolab measures the torque (expressed in Nm) produced by dough between two kneading arms and temperature changes, in order to simulate the bread making process. The dough sample (90 g) was subjected to dual-mixing (80 rpm) during a heating and cooling programme and the following protocol was used: initial equilibrium at 30 °C for 8 min, heating to 90 °C with 4 °C/min, holding at 90 °C for 7 min, cooling to 50 °C with 4 °C/min and holding at 50 °C for 5 min. The analysis was repeated 3 times for each sample. From the recorded curves, dough mixing parameters were calculated with the help of Mixolab software (version 4.0.8).

The first part of the Mixolab curve (mainly, the C1 and C2 parameters) shows the properties of proteins, while the other parameters give information on the starch behaviour. C1 is used to calculate the water absorption of the flour (%) in order to produce a maximum torque of 1.1 Nm during the mixing. Other parameters from the curve are: dough development time (min): time required to reach the maximum torque; stability (min): mixing resistance of dough (the elapsed time at which the torque produced is kept at 1.1 Nm); C2 (Nm): torque associated with protein weakening due to mechanical work and temperature increase; C3 (Nm): measures the starch gelatinisation; C4 (Nm): measures the stability of the starch gel formed; C5 (Nm): measures the starch retrogradation during the cooling period (Dubat, 2013; Torbica *et al.*, 2010).

Bread making process

The bread formula consisted of 300 g soryz flour with replacement by soy flour at 0% (control), 5% (SS_5) and 10% (SS_10), 210 g maize starch, 3 g carboxymethylcellulose, 27 g sugar, 6 g salt, 12 g oil, 24 g fresh yeast and 320 ml water. The ingredients were mixed with a 2-speed mixer (Diosna, Osnabrück, Germany) for 5 min. The dough was placed in baking pans, proofed at 40 °C and 65% relative humidity for 30 min (M.C.E. Meccanica, Buttapietra, Italy) and baked at 200 °C for 30 min (Mondial Forni, Verona, Italy). The loaves were removed from the pans and cooled at room temperature before analysis.

Bread analysis

Bread volume was determined by rapeseed displacement method (AACC, 2010), while for crumb porosity measurements, a cylindrical piece of crumb was cut from a 60 mm slice taken from the centre of the bread loaf and weighed (ASRO, 2007).

Colour of bread crumbs was measured using a CM-5 spectrophotometer (Konica Minolta Sensing, Inc., Osaka, Japan) with a D65 illuminant and a 10° observer angle. Before measurements, the instrument was calibrated against the black and white tiles. The colour was determined on ten different points on the same slice (20 mm thickness) taken from the centre of the bread and it was expressed as L* (lightness), a* (redness) and b* (yellowness) values.

Bread crumb texture properties were determined with an Instron Texture Analyzer equipped with a 50 N load cell (model 5944, Illinois Tool Works Inc., Glenview, IL, USA). Bread slices (20 mm thickness) cut from the centre of the loaves were double compressed to 50% of sample original height at speed rate of 100 mm/min, using a 12-mm-diameter cylindrical probe. Between compressions, a resting time of 10 s was applied. Hardness, springiness, cohesiveness and chewiness were calculated from the texture curves (Bourne, 1978). The average values of 6 determinations were reported.

Evaluation of the chemical parameters (moisture, protein, fat, fibre) for the bread samples studied was determined according to AOAC (2005) methods. Energy value was determined by the formula: (g protein × 4) + (g fat × 9) + (g carbohydrates × 4) + (g fibre × 2) (European Commission, 2011).

Digital images of bread were done on 20-mm-thick slices taken from the central part of the loaf, using a scanner (Sharp MX-2614) with 600 dpi resolution.

Statistical analysis

The analysis was carried out in triplicate and the results were expressed as mean ± standard deviation. Statistical differences between mean values were compared using Tukey test (Minitab®17 software, Minitab Ltd., Coventry, UK). *P*-value lower than 0.05 was considered to be significant. Pearson correlations analysis was performed.

3. Results and discussion

Proximal composition of gluten-free flours

Diversification of gluten-free flours has the potential to enhance the nutritional properties of gluten-free products. In general, the nutritive and quality value of the gluten-free products is lower than conventional products (Arendt and Dal Bello, 2008). There are a lot of gluten-free sources which can be used in gluten-free bakery formulations.

The gluten content analysed in the soryz flour was less 5 mg/kg and according to European Commission (2009) through regulation number 41/2009 – which states that 'Foodstuffs for people intolerant to gluten … shall not contain a level of gluten exceeding 20 mg/kg', soryz flour is referred as a gluten-free cereal grain and its products are safe for celiac people.

The compositional analysis of gluten-free flours from different sources investigated in this study is shown in Table 1. The protein and dietary fibre content of soy and oat flours were higher compared to the other sources. Starch is the major component of soryz flour. In terms

Table 1. Chemical composition (% dry matter) of gluten-free flours compared to wheat and soy flours.[1]

Flour	Protein	Fat	Ash	Fibre	Starch
Soryz	8.07±0.04e	1.66±0.05f	0.84±0.01f	3.53±0.07f	78.75±0.69b
Whole rice	8.16±0.08e	3.24±0.07d	1.49±0.02e	5.26±0.11e	75.69±0.28c
Whole oat	15.14±0.11b	7.94±0.13b	1.67±0.02d	10.67±0.12b	55.68±0.16e
Soy	45.17±0.22a	9.76±0.11a	5.51±0.07a	17.69±0.25a	4.13±0.04g
Quinoa	15.00±0.11b	6.87±0.11c	2.65±0.04b	8.04±0.17d	53.36±0.31f
Teff	11.65±0.08d	2.69±0.07e	2.24±0.03c	9.20±0.11c	64.81±0.15d
Wheat	13.16±0.07c	0.92±0.01g	0.72±0.03g	2.79±0.12g	80.88±0.67a

[1] The results are expressed as mean ± standard deviation (n=3). Values followed by different letters in columns are significantly different (*P*<0.05).

of protein content, soryz was similar to whole rice flour with significantly lower content than oat, soy, quinoa and teff flours. The flours composition influences the thermo-mechanical properties of the dough in terms of water absorption, dough development time and dough stability.

Thermo-mechanical properties of gluten-free flours

Figure 1 shows the curves obtained from Mixolab test for the gluten-free flours studied, while the corresponding parameters are summarised in Table 2. Besides gluten-free flours, a typical curve obtained for wheat flour (Figure 1A) was included as a comparison for the shape of the curve.

Soryz flour has an atypical curve shape (very low consistency) until the gelatinisation temperature is reached (Figure 1G). Thus, soryz flour has optimal properties during the heating period (above 60 °C) where the curve shows information about starch properties. The Mixolab profile of soryz flour resembles to that of maize starch as it was determined by Torbica *et al.* (2008).

Soryz protein is significantly influenced during heating than that of the other gluten-free flours studied. This behaviour cannot be attributed to the protein content as soryz and whole rice flours have similar concentration (Table 1).

As it can be seen in Figure 1B and 1C, the shape of the Mixolab curve for whole rice and oat flours were more similar to that of the wheat flour (Figure 1A) as compared to the other samples. On the other side, quinoa and teff were characterised by a sharp C1 peak (Figure 1E and 1F). Quinoa and teff flours had a sharp increase in the torque with the fastest dough development, and, accordingly, the maximum torque of 1.1 Nm was achieved in a shorter time ($P<0.05$) than the other flours. The torque decreased quickly within 1 min, indicating a lower stability of quinoa and teff flours (Figure 1E and 1F). Also, soryz flour exhibited lower stability when compared to the other gluten-free flours which corroborates the weakening of the protein network. Thus, soryz, quinoa and teff flours did not present stable interval at 1.1 Nm unlike rice, oat and soy flours.

The dough of soy and whole oat flours had improved stability ($P<0.05$) compared to the others and a significantly higher development time ($P<0.05$) was needed to reach the maximum torque during the mixing because of the longer periods needed to bind water. A highly positive correlation was noted between water absorption and dough development time ($r=0.78$; $P<0.05$). Moreover, a flour with high fibre content will need a longer development time to absorb water. Thus, a good correlation ($r=0.71$; $P>0.05$) was noted between fibre content and dough development time.

In gluten-free bread making process, the key role is attributed to the amount of water absorbed by flours (Marco and Rosell, 2008). Water absorption capacity is enhanced by proteins and carbohydrates due to their hydrophilic parts such as polar and charged side chains (Nyembwe *et al.*, 2018). Also, higher water absorption for soy and whole oat flour than for the other gluten-free flours could be attributed to the higher level of fibres which compete with the protein for water. However, no specific correlation between water absorption and chemical composition of flours was found.

When dough is subjected to double constraint (kneading and temperature), torque decreases due to the beginning of the protein destabilisation and unfolding (C2 value) (Dubat, 2013).

Whole oat flour exhibited higher value of the protein weakening (C2) suggesting that oat produced dough with strong mixing resistance to the deformation during kneading and heating. A highly positive correlation was found between C2 and dough stability ($r=0.88$; $P<0.05$).

Thus, samples with resistant protein network (high C2), prevent the dough from developing correctly, producing a smaller bread.

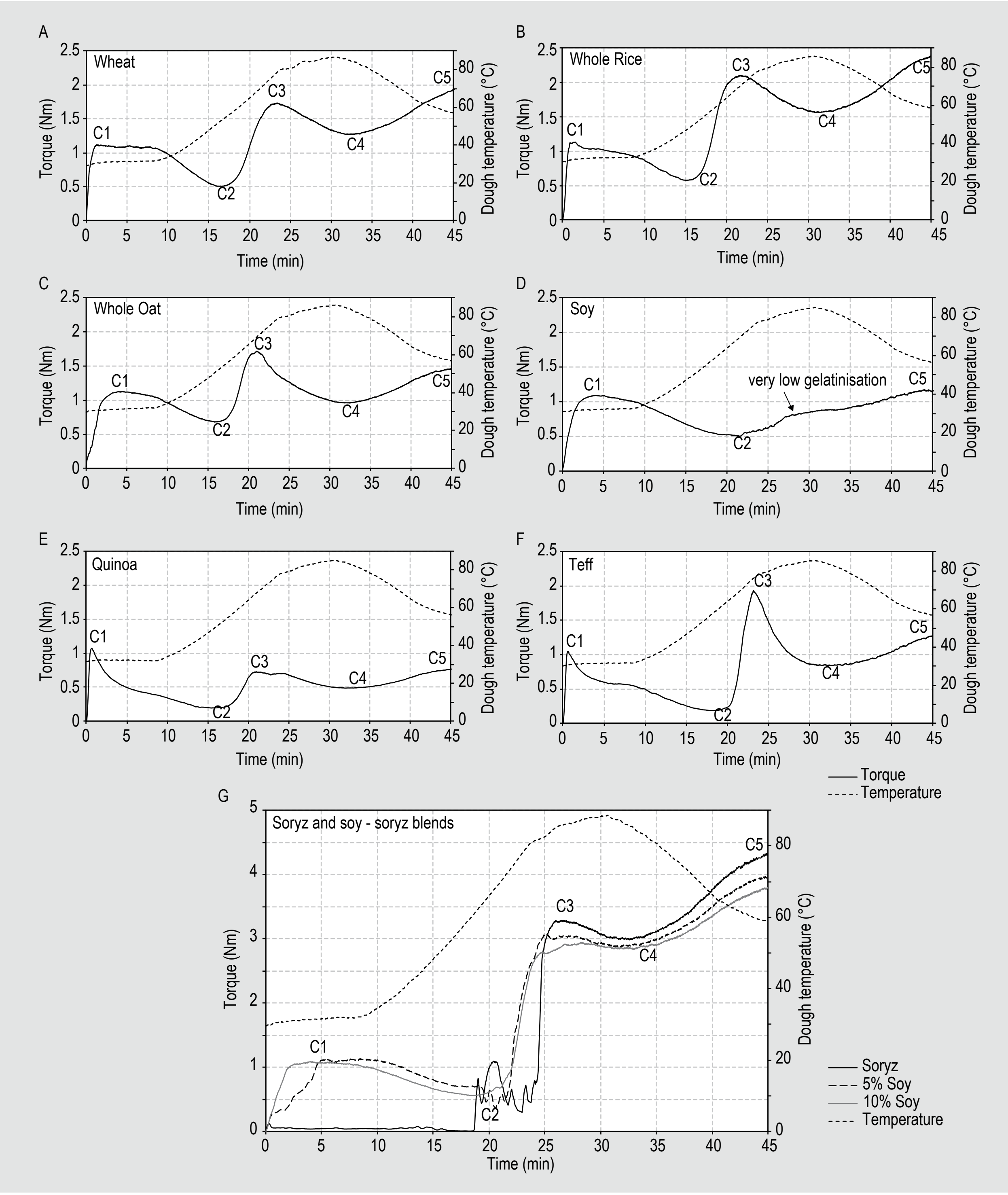

Figure 1. Thermo-mechanical properties of different flours: (A) wheat; (B) whole rice; (C) whole oat; (D) soy; (E) quinoa; (F) teff; (G) soryz and soy-soryz blends. C2 = protein weakening; C3 = starch gelatinisation; C4 = starch gel stability; C5 = starch retrogradation.

The significantly lower value ($P<0.05$) of C2 in case of quinoa and teff flour revealed a reduced strength of the protein network. A reduced strength means a more intensive weakening of the protein network. The strengthening of the protein network varies as follows: whole oat > whole rice > soy = wheat > quinoa = teff > soryz. Soryz dough is characterised by a lack of structure forming ability of soryz flour proteins compared to the samples studied.

After reaching the C2 values and on further temperature increasing, the torque increases up to a maximum torque C3 which corresponds to starch gelatinisation.

Table 2. Mixolab parameters of different flours.[1]

Flour[2]	Development time (min)	Stability (min)	WA (%)	C2 (Nm)	C3 (Nm)	C4 (Nm)	C5 (Nm)
Wheat	1.33±0.06c	9.38±0.03a	61.4±0f	0.51±0.01b	1.73±0.03d	1.27±0.03c	1.92±0.03d
Whole rice	1.56±0.06c	5.84±0.23c	68.67±0.29d	0.56±0.02b	2.07±0.04c	1.58±0.03b	2.46±0.09c
Whole oat	4.23±0.17b	7.73±0.2b	86.5±0.35a	0.68±0.02a	1.73±0.02d	0.96±0.01d	1.47±0.02e
Soy	4.15±0.16b	7.93±0.22b	74.57±0.58b	0.51±0.01b	0.59±0.01g	0.87±0.03d	1.19±0.02e
Quinoa	0.60±0.03d	0.78±0.05d	71.33±0.40c	0.19±0.01c	0.73±0.01f	0.48±0e	0.78±0.03f
Teff	0.61±0.07d	0.66±0.08d	64.33±0.58e	0.19±0.0c	1.51±0.08e	0.86±0.03d	1.30±0.02e
Soryz	-	-	50.0±0h	0.05±0d	3.27±0.02a	2.94±0.08a	4.35±0.05a
SS_5	8.53±0.35a	7.63±0.74b	54.3±0.6g	0.51±0.05b	2.98±0.09b	2.76±0.13a	3.62±0.32b
SS_10	4.51±0.49b	8.33±0.25b	54.3±0g	0.55±0.01b	2.88±0.07b	2.79±0.08a	3.72±0.11b

[1] Data are presented as mean ± standard deviation (n=3). Values followed by different letters in columns are significantly different (P<0.05).
[2] SS_5: soryz flour with 5% soy flour addition; SS_10: soryz flour with 10% soy flour addition.

Significant differences between C3 values (P<0.05) can be observed by comparing the tested gluten-free dough samples (Table 2). The highest C3 value was obtained for soryz, followed by whole rice flour. Thus, soryz starch behaviour was characterised by the highest gelling ability. Debet and Gidley (2006) reported that lower protein and lipid content is associated with higher peak viscosity which correspond to higher starch granule swelling behaviour. Thus, a negative correlation was found between C3 value and protein content of the gluten-free flours studied (r=-0.66; P>0.05). The same correlation was observed for lipid content (r=-0.68; P>0.05). Moreover, a higher starch content was correlated with higher gelatinisation as it was exhibited by the value of C3 (r=0.76; P>0.05).

On soy flour dough it was observed the disappearance of the gelatinisation peak (C3) compared with the other flours. Soy flour has a very low gelatinisation capacity mainly attributed to the low starch content and a very slight rebound at 27 min. was noticed.

The difference between C3 and C4 is related to amylase activity (Collar *et al.*, 2007). Namely, the greater the difference is, the greater the amylase activity is. Oat dough presented a significantly higher C3-C4 value of 0.77 (P<0.05) in comparison to the other samples: teff (0.63), rice (0.49), soryz (0.33), soy (0.28) and quinoa (0.25). This can be explained by the high degree of amylase activities in oat flour (Singh *et al.*, 2013).

Starch retrogradation is one of the main factors that cause the bread staling (Gray and Bemiller, 2003). Starch retrogradation is influenced mainly by botanical source of the starch and amylose/amylopectin ratio (Ottenhof and Farhat, 2004).

In the cooling stage, soryz flour presented the highest value for C5, indicating a different type of starch. The very high value for retrogradation in soryz is likely because of the higher degree of starch gelatinisation in the heating phase. A highly positive correlation was between C3 and C5 parameters (r=0.94; P<0.05).

A flour with a low retrogradation capacity (low C5 value) is recommendable to ensure a longer product shelf-life. Quinoa flours can improve product shelf-life due to the lowest starch retrogradation (P<0.05). The retrogradation is practically equivalent for both soy and teff flours because there were no significant differences (P>0.05) in C5 parameter.

A lower C5 value is correlated with the anti-staling effects. Thus, based on measured C5 values, the anti-staling effectiveness in bakery products (for example bread and cakes) decreases in the order: quinoa < soy < teff < whole oat < wheat < whole rice < soryz.

Kahraman *et al.* (2008) stated that in terms of good cake quality, the flours should present low C2, C3, C4 and C5 values. Therefore, quinoa flour could be the most suitable for cake dough.

Different studies found correlations between dough parameters obtained during the heating and cooling cycles with the Mixolab and the instrumental quality parameters, like specific volume and hardness assessed by texture analysis (Krupa-Kozak *et al.*, 2012, 2013; Marco and Rosell, 2008). Dough consistency during mixing (C1) and dough consistency after cooling (C5) are useful predictors of perceived crumb hardness of gluten-free bread products (Matos and Rosell, 2013).

Vilmane and Straumite (2014) showed that soy flour incorporation increased gluten-free dough's rheological properties. Thus, in order to improve the soryz dough quality, soy-soryz blends were considered in the Mixolab study (Table 2). Soryz flour was replaced by 5% and 10% soy flour, respectively (Figure 1G). Incorporation of soy flour impacts significantly the protein part of the curve by strengthening the protein network (significant increase of C2 value) compared to 100% soryz flour. Addition of soy flour showed higher dough stability when compared to soryz (Table 2), which confirms the strengthening of the protein network. Soy flour incorporation resulted in a significant decrease ($P<0.05$) in C3 and C5 value indicating a higher starch pasting ability and lower starch retrogradation in comparison to soryz flour, respectively. These could be explained by the higher protein and fat content of soy flour and lipid/amylose complex forming ability (Hadnađev *et al.*, 2011).

However, no significant differences ($P>0.05$) between the influence of 5 and 10% soy flour on soryz dough rheological properties (dough stability, water absorption, C2, C3, C4 and C5 values) were found.

Bread characteristics

Since decades, fortification of bread with soy flour is considered in order to increase the protein content and balance the essential amino acid composition (Melini *et al.*, 2017; Tsen and Hoover, 1973). In order to increase the nutritional value of soryz bread, addition of 5% and 10% soy flour, respectively, was considered.

Image analysis of bread slices scanned is presented in Figure 2, while the characteristics of bread samples are summarised in Table 3.

A significant decrease in bread volume, porosity and lightness ($P<0.05$) was observed as the level of soy flour addition increased in the bread receipt. Soy-soryz breads were darker than the control soryz bread. The a* and b* values of the crumb increased ($P<0.05$) relative to soy addition indicating the formation of a more redness and yellowness crumb colour. Soryz bread prepared with 10% soy addition showed the highest hardness ($P<0.05$) than the other formulations. Bread springiness and chewiness decreased slowly, but the difference was not significant ($P>0.05$) between control and bread with soy addition. The results of this study are in line with other researches which showed that soy addition contribute to the loss of bread volume and increase of crumb hardness (Melini *et al.*, 2017; Sabanis and Tzia, 2011).

When soy flour is blended with soryz flour in bread formulations, the protein content is 1.25-1.5-fold higher than control soryz bread. With soy addition, the energy value of soryz bread is significantly increased by 3.3% (for SS_5 bread) and 4.8% (for SS_10 bread), respectively.

The outcomes of this study showed that the potential of soryz flour to be used in bread manufacturing together with other ingredients in order to improve the bread nutritional value.

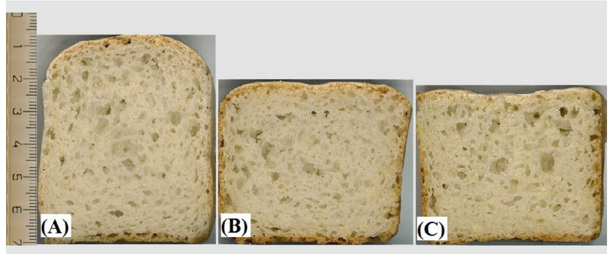

Figure 2. Digital images obtained from the central part of the breads. (A) control soryz bread; (B) soryz bread with 5% soy flour addition; (C) soryz bread with 10% soy flour addition.

Table 3. Physical (volume, porosity and colour), textural (hardness, springiness, cohesiveness and chewiness) and chemical (moisture, protein, fat, fibre and energy value) parameters of soryz breads.[1,2]

Bread sample	Bread S	Bread SS_5	Bread SS_10
Volume (cm^3/100 g)	212±2a	203±1b	184±2c
Crumb porosity (%)	68.3±0.6a	64.9±0.1b	60.6±0.6c
L*	74.7±0.2a	71.8±0.2b	70.8±0.1c
a*	1.1±0c	1.4±0b	1.8±0a
b*	20.2±0.1c	22.4±0.1b	24.2±0.1a
Hardness (N)	11.2±1.1b	11.3±0.8b	15.2±1.5a
Springiness	0.9±0a	0.9±0.1a	0.8±0.2a
Cohesiveness	0.4±0a	0.4±0a	0.3±0b
Chewiness (N)	4.5±0.6a	4.1±0.5a	4.1±0.6a
Moisture (%)	42.3±0.1a	40.6±0.1b	39.9±0.3c
Protein (%)	2.8±0.1c	3.5±0.1b	4.1±0.1a
Fat (%)	1.5±0c	1.6±0.1b	1.9±0.1a
Fibre (%)	1.2±0.1c	1.5±0.1b	1.8±0.1a
Energy value (kcal/100 g)	231.5±0.3c	239.2±0.5b	242.8±0.7a

[1] Values are means ± standard deviation: n=3 determinations for volume, porosity and chemical parameters; n=6 for texture parameters; n=10 determinations for colour parameters. Values in the same row followed by different letters are significantly different at $P<0.05$.
[2] Bread S: control soryz bread; Bread SS_5: soryz bread with 5% soy flour addition; Bread SS_10: soryz bread with 10% soy flour addition.

4. Conclusions

Mixolab showed a complete gluten-free dough characterisation regarding protein network, starch and amylase activity. Based on Mixolab data, useful information is obtained regarding the rheological behaviour of soryz flour. Soryz had lower water absorption, lower stability, weaker protein network as well as higher starch gelatinisation and retrogradation properties in comparison to the other gluten-free flours studied.

The rheological behaviour of flours can predict some of the properties of new products. Thus, the knowledge on the rheological behaviour of soryz flour would bring forth for developing gluten-free bakery products. Bread formulations on soryz flour as well as soy-soryz blends were investigated. In order to improve bread nutritional value and not to alter the sensorial properties, a percentage of up to 10% soy addition was proposed.

Acknowledgements

This study was achieved through Core Program, with the support of the Ministry of Research and Innovation (MCI), contract 25N/2018, project PN 18 02 02 01.

References

American Association of Cereal Chemists (AACC), 2010. Method 10-05.01. Guidelines for measurement of volume by rapeseed displacement, 11th edition. AACC International Approved Methods, St. Paul, MN, USA.

Arendt, E.K. and Dal Bello, F., 2008. Gluten-free cereal products and beverages. Academic Press, Cambridge, MA, USA, 469 pp.

Asociația de Standardizare din România (ASRO), 2007. SR 91, 2007. Bread and fresh pastry products. Methods of analysis. Available at: https://tinyurl.com/y2vxrw6f. (in Romanian)

Association of Official Analytical Chemists (AOAC), 2005. Official methods of analysis of AOAC International. AOAC, Gaithersburg, MD, USA.

Bourne, M.C., 1978. Texture profile analysis. Food Technology 32: 62-66.

Capriles, V.D. and Arêas, J.A.G., 2014. Novel approaches in gluten-free breadmaking: interface between food science, nutrition, and health. Comprehensive Reviews in Food Science and Food Safety 13(5): 871-890.

Collar, C., Bollain, C. and Rossel, C.M., 2007. Rheological behaviour of formulated bread doughs during mixing and heating. Food Science and Technology International 13: 99-107.

Debet, M.R. and Gidley, M.J., 2006. Three classes of starch granule swelling: influence of surface proteins and lipids. Carbohydrate Polymers 64: 452-465.

Demirkesen, I., Mert, B., Sumnu, G. and Sahin, S., 2010, Utilization of chestnut flour in gluten-free bread formulations. Journal of Food Engineering 101: 329-336.

Dubat, A., 2013. The mixolab. In: Dubat, A., Rosell, C.M. and Gallagher, E. (eds.) Mixolab. A new approach to rheology. AACC International, Inc., St. Paul, MN, USA, pp. 3-13.

European Commision, 2009. Commission regulation (EC) No. 41/2009 of 20/01/2009 concerning the composition and labeling of foodstuffs suitable for people intolerant to gluten. Official Journal of the European Union L 16(3): 3-5.

European Commission, 2011. Commission Regulation (EC) No. 1169/2011 of 25/10/2011, on the Provision of Food Information to Consumers. Official Journal of the European Union L 304: 18-63.

Gobbetti, M., Pontonio, E., Filannino, P., Rizzello, C.G., De Angelis, M. and Di Cagno, R., 2018. How to improve the gluten-free diet: the state of the art from a food science perspective. Food Research International 110: 22-32.

Gray, J.A. and Bemiller, J.N., 2003. Bread staling: molecular basis and control. Comprehensive Reviews in Food Science and Food Safety 2: 1-21.

Hadnađev, T.D., Torbica, A. and Hadnađev, M., 2011. Rheological properties of wheat flour substitutes/alternative crops assessed by Mixolab. 11th International Congress on Engineering and Food. Procedia Food Science 1: 328-334.

Huang, W., Li, L., Wanga, F., Wana, J., Tilley, M., Ren, C. and Wuc, S., 2010. Effects of transglutaminase on the rheological and Mixolab thermomechanical characteristics of oat dough. Food Chemistry 121: 934-939.

International Association for Cereal Science and Technology (ICC), 2006. ICC Standard No. 173. Whole meal and flour from *T. aestivum* – determination of rheological behavior as a function of mixing and temperature increase. Available at: https://tinyurl.com/y5plbwe5.

Kahraman, G., Harsa, S., Lucisano, M. and Cappa, C., 2018. Physicochemical and rheological properties of rice-based gluten-free blends containing differently treated chickpea flours. LWT – Food Science and Technology 98: 276-282.

Kahraman, K., Sakiyan, O., Ozturk, S., Koksel, H., Sumnu, G. and Dubat, A., 2008. Utilization of Mixolab® to predict the suitable of flours in terms of cake quality. European Food Research and Technology 227: 565-570.

Krupa-Kozak, U., Altamirano-Fortoul, R., Wronkowska, M. and Rosell, C.M., 2012. Breadmaking performance and technological characteristic of gluten-free bread with inulin supplemented with calcium salts. European Food Research Technology 235: 545-554.

Krupa-Kozak, U., Bączek, N. and Rosell, C.M., 2013. Application of dairy proteins as technological and nutritional improvers of calcium-supplemented gluten-free bread. Nutrients 5: 4503-4520.

Lazaridou, A., Duta, D., Papageorgiou, M., Belc, N. and Biliaderis, C.G., 2007. Effects of hydrocolloids on dough rheology and bread quality parameters in gluten-free formulations. Journal of Food Engineering 79(3): 1033-1047.

Marco, C. and Rosell, C.M., 2008. Functional and rheological properties of protein enriched gluten free composite flours. Journal of Food Engineering 88: 94-103.

Marti, A., Marengo, M., Bonomi, F., Casiraghi, M.C., Franzetti, L, Pagani, M.A. and Iametti, S., 2017. Molecular features of fermented teff flour relate to its suitability for the production of enriched gluten-free bread. LWT – Food Science and Technology 78: 296-302.

Matos, M.E. and Rosell, C.M., 2013. Quality indicators of rice based gluten free bread-like products: relationships between dough rheology and quality characteristics. Food Bioprocess Technology 6: 2331-2341.

Melini, F., Melini, V., Luziatelli, F. and Ruzzi, M., 2017. Current and forward-looking approaches to technological and nutritional improvements of gluten-free bread with legume flours: a critical review. Comprehensive Reviews in Food Science and Food Safety 16: 1101-1122.

Monthe, O.C., Grosmaire, L., Nguimbou, R.M., Dahdouh, L., Ricci, J., Tran, T. and Ndjouenkeu, R., 2019. Rheological and textural properties of gluten-free doughs and breads based on fermented cassava, sweet potato and sorghum mixed flours. LWT – Food Science and Technology 101: 575-582.

Moore, M.M., Dal Bello, F. and Arendt, E.K., 2008. Sourdough fermented by *Lactobacillus plantarum* FST 1.7 improves the quality and shelf life of gluten-free bread. European Food Research and Technology 226: 1309-1316.

Nyembwe, P.M., De Kock, H.L. and Taylor, J.R.N., 2018. Potential of defatted marama flour-cassava starch composites to produce functional gluten-free bread-type dough. LWT – Food Science and Technology 92: 429-434.

Ottenhof, M.-A. and Farhat, I.A., 2004. Starch retrogradation. Biotechnology and Genetic Engineering Reviews 21(1): 215-228.

Rosell, C.M., 2013. Gluten-free cereals and flours and the Mixolab. In: Dubat, A., Rosell, C.M. and Gallagher, E. (eds.) Mixolab. A new approach to rheology. AACC International, Inc., St. Paul, MN, USA, pp. 65-70.

Sabanis, D. and Tzia, C., 2011. Effect of hydrocolloids on selected properties of gluten-free dough and bread. Food Science and Technology International 17(4): 279-291.

Schober, T.J. and Bean, S.R., 2008. Sorghum and maize. In: Arendt, E.K. and Dal Bello, F. (eds.) Gluten-free cereal products and beverages. Elsevier Inc., New York, NY, USA, pp. 101-118.

Schoenlechner, R., Siebenhandl, S. and Berghofer, E., 2008. Pseudocereals. In: Arendt, E.K. and Dal Bello, F. (eds.) Gluten-free cereal products and beverages. Elsevier Inc., New York, NY, USA, pp. 149-190.

Singh, R., De, S. and Belkheir, A., 2013. Avena sativa (Oat), a potential neutraceutical and therapeutic agent: an overview. Critical Review in Food Science and Nutrition 53: 126-144.

Torbica, A., Hadnađev, M. and Dapčević, T., 2010. Rheological, textural and sensory properties of gluten-free bread formulations based on rice and buckwheat flour. Food Hydrocolloids 24(6): 626-632.

Torbica, A., Hadnađev, M., Dokić, P. and Sakač, M., 2008. Mixolab profiles of gluten free products ingredients. Food Processing, Quality and Safety 35: 19-26.

Tsen, C.C. and Hoover, W.J., 1973. High-protein bread from wheat flour fortified with full-fat soy flour. Cereal Chemistry 50(1): 7-16.

Turkut, G.M., Cakmak, H., Kumcuoglu, S. and Tavman, S., 2016. Effect of quinoa flour on gluten-free bread batter rheology and bread quality. Journal of Cereal Science 69: 174-181.

Vilmane, L. and Straumite, E., 2014. The use of soy flour in yellow maize-amaranth gluten-free bread production. Rural Sustainability Research 31(1): 1-11. https://doi.org/10.2478/plua–2014–0001.