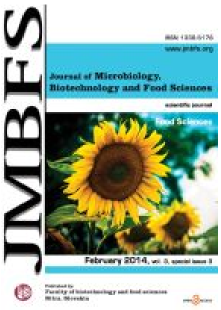

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RHEOLOGICAL CHARACTERISTICS OF GLUTEN-FREE DOUGH

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ABSTRACT

Dynamic oscillation rheometry was used to determine the viscoelastic properties of gluten-free dough prepared from amaranth, chickpea, millet, corn, quinoa, buckwheat and rice flours. The viscoelastic properties was described by storage modulus G´, loss modulus G´´ and phase angle tg(δ). The relationship between viscoelastic properties of gluten-free dough and bread-making quality was evaluated. The results of this study indicated that dynamic oscillation rheometry may be used to differentiate the bread-making quality of gluten-free flour. Bread-making quality of gluten-free flour is the best characterised by curve slope of storage modulus G´and phase angle tg(δ) while bread made from the flour with storage modulus and phase angle with non-linear slope in low deformation frequencies 0.01–0.10 Hz achieved the largest volume.

Keywords: gluten-free, dough, rheology, bread

INTRODUCTION

Rheology studies the response of the material on various deformations. Measured rheological behaviour can be used to predict product's end-quality. Rheological techniques are commonly categorised according to the type of strain imposed: e.g. compression, extension, shear, torsion etc. The main techniques used for measuring cereal properties have traditionally been divided into descriptive empirical techniques and fundamental measurements (**Bloksma and Bushuk, 1988**).

Empirical methods have been used for testing dough rheological properties for a long time. The most often used equipment used for testing rheological characteristics of food material are penetrometer, farinograph, mixograph, extensograph, alveograph etc. (**Dobraszczyk and Morgenstern, 2003**). Empirical tests often have very simple methodology. Many of them are designed as so-called single point tests, in which only one of the measured parameters is selected as the reference. The most widely used instrument for testing the rheological properties of dough is Brabender farinograph. Farinograph is used to record changes in the dough's consistency during the kneading. Brabender extensograph is designed for measuring the stretching properties of dough until rupture. Fariograph has few disadvantages, such as a relatively large amount of test sample required for one test (300 g flour) and expressing the results in units specific to each device. Several alternative methods required smaller amounts of test sample to be developed (**Kieffer *et al.*, 1998**). These alternative methods are commonly used despite their insufficiencies, especially lower correlation between the results and the end-product quality. (**Hsam *et al.*, 2001; Dunnewind *et al.*, 2003; Tronsmo *et al.*, 2003; Wang *et al.*, 2004; Kieffer *et al.*, 2007**).

The most common type of fundamental rheological tests used in material testing is small deformation dynamic shear oscillation (**Ferry, 1980; Barnes *et al.*, 1989; Cosgrove *et al.*, 2005**). This method is applicable to testing of cereal as well. The material is subjected to either a stress or a frequency harmonically varying with time. The measurement has to be performed in the linear viscoelastic region in which the properties of the material are independent on the shear strain and stress and are only a function of time or frequency. Another advantage of the measurement in the linear area is less structural damage of the test sample and better interpretation of data. Dynamic oscillatory rheometry is used to model dough behaviour in various stages of processing (**Addo *et al.*, 2001; Peighambardoust *et al.*, 2005; Singh a Bhattacharya, 2005; Hicks *et al.*, 2011; Ktenioudaki *et al.*, 2011; Upadhyay *et al.*, 2012**) to evaluate influence of the formulation components on the rheological dough properties (**Rosell *et al.*, 2001; Maforimbo *et al.*, 2006; Sozer, 2009; Moreira *et al.*, 2011a,b; Ahmed *et al.*, 2013**) to predict the technological quality of the dough and pastry (**Khatkar *et al.*, 1995; Van Bockstaele *et al.*, 2008; Ktenioudaki *et al.*, 2011; Stojceska a Butler, 2012**). Disadvantages of the dynamic oscillation method include conditions of the deformation which are often not simular with practical processing situations because they are performed at rates and conditions very different from those experienced by the dough during processing (**Dobraszczyk and Morgenstern, 2003**) and according to these authors the results obtained by dynamic oscillation rheometry are not practically applicable. This method is however commonly used to evaluate rheological properties of wheat dough by many authors (**Khatkar *et al.*, 1995; Sozer, 2009; Lamacchia *et al.*, 2010; Moreira *et al.*, 2012; Ahmed *et al.*, 2013; Moreira *et al.*, 2013a; Moreira *et al.*, 2013b**). Unfortunately measurement conditions selected by the authors varied which makes comparison of the results obtained by the authors quite difficult.

The aim of the study was, (i) to determine the rheological properties of gluten-free dough under defined conditions, (ii) to compare the characteristics of each gluten-free dough, and (iii) verify the applicability of dynamic oscillation rheometry in order to test bread-making quality of gluten-free flour.

MATERIAL AND METHODS

The work was conducted on amaranth (Josef Vince Jihlava, CZ), chickpea, millet, rice (Natura Hustopeče, CZ), corn (Mlýn Herber, Ltd. Opava Vávrovice, CZ), quinoa (ASO Zdravý život Hranice, CZ) and buckwheat (Pohankový mlýn Zdeněk Šmajstrla Frenštát pod Radhoštěm, CZ) flours. The commercially milled wheat T530 and rye flour (Penam, a. s., Mlýn Kroměříž, CZ) were used as control samples. Chemicals used for testing were of p.a. purity. Dynamic oscillation measurements were performed on a dough prepared from ultra-pure water with electrical resistivity of 18.2 MΩ·cm.

Dynamic oscillation rheometry

Dynamic oscillation rheometry was performed on rheometer HAAKE RheoStress 1 (Thermo Scientific, ČR). The geometry consisted of parallel plates 35 mm in diameter P35 Ti L. Dough was prepared from 10,00 g of flour and water, required to prepare dough with optimal consistency 500 FU (**Silva-Sánchez *et al.*, 2004; Sivaramakrishnan *et al.*, 2004; Marco a Rosell, 2008**). Prepared dough ball was placed into proofing box (30 °C) for 5 min relaxation. Relaxed dough ball was placed between the plates and the gap was adjusted to 1.500 mm and the edges were cut off with a spatula. Silicone lubricant M15 (Lučební závody a.s. Kolín, ČR) was applied to the exposed surface of the dough to prevent moisture lost during measurement. The dough rested between the plates for another 5 minutes with the plate temperature of 30 °C before testing in order for the residual stresses to relax. Stress sweep tests (1 Hz at 30 °C) were conducted in order to determine the linear viscoelastic region (**Cosgrove, 2005**) of all samples; 50 Pa stress value was chosen for frequency tests. Frequency sweep tests ranging 0.01 to 10 Hz were performed at the plate temperature of 30 °C. Storage modulus G´, lost modulus G´´ and phase angle $tg(\delta) = \frac{G''}{G'}$ were recorded. The storage and loss moduli values and values of phase angle used to determine the average data turned out to be accurate to better than ±10%.

Bread-making procedure

A basic bread formula, based on flour weight, consisted of 300 g of flour (14% mb), water up to 500 FU consistency, 1.8% dried yeast, 1.68% sucrose, 1.5% salt and 0,005% ascorbic acid. Flour, half of water, salt and ascorbic acid was mixed for 3 minutes. Yeast activated in the sucrose solution was added and dough was stirred for the next 6 minutes. Dough was divided into 3 pieces, poured into a baking form and fermented for 20 minutes at 30 °C. The breads were baked in an electric oven for 20 min at 180 °C. The bread quality attributes were evaluated after cooling for 20 h at room temperature. Bread quality analysis included bread volumes was determined in plastic granulate.

Statistical analyses

The significance of correlation between bread volume and storage modulus, loss modulus and phase angle was determined by Pearson correlation coefficient at $\alpha = 0.05$ significance level. Analysis of variance (ANOVA) was used to analyze the differences between samples at $\alpha = 0.01$ significance level (Hebák et al., 2004). All statistical analyses were performed using Statistica Cz 9.1 software (StatSoft, Inc. U.S.A.).

RESULTS AND DISCUSSION

Dynamic oscillation rheometry measurement requires storage and loss moduli G ', G'' and phase angle tg(δ) to only be a function of time or frequency and to be independent on the applied shear stress. Measurements under these conditions guarantee the structure of sample is not damaged during measurement and data can be better interpreted (**Cosgrove, 2005**). It was experimentally found that linear viscoelastic region of gluten-free flours, control wheat and rye flour was in the range of 10-990 Pa shear stress; 50 Pa shear stress was selected for further measurements.
The storage modulus G´ of gluten-free dough, control wheat and rye dough was greater than loss modulus G´´ (Fig. 1), indicating the predominance of elastic characteristics (**Sivaramakrishnan *et al.*, 2004; Lamacchia *et al.*, 2010**). Measured values of moduli indicated that dough was in the form of the weak gel in the investigated range of frequencies 0.10–10.0 Hz (**Richardson *et al.*, 1989**). The values of storage G´ and loss G´´ modulus of gluten-free dough in the investigated range of frequencies were significantly greater than values of control wheat and rye dough and gluten-free dough were firmer that control dough. The values of gluten-free storage modulus G´ increased linearly with increasing frequency in the range of higher frequencies (0.10–10.0 Hz). In the range of lower frequencies (0.01–0.10 Hz), storage modulus recorded for rice, quinoa, millet, corn and buckwheat dough increased linearly with increasing frequencies, while modulus slope recorded for amaranth, chickpea and control wheat and rye dough was not linear indicating dough softening. The frequency dependence of loss modulus G´´ was similar to storage modulus G´. Values of loss modulus of gluten-free dough were significantly greater that values of control wheat and rye dough (Fig 2). A light, nearly linear increase was recorded in 0.01–0.10 Hz frequencies. A non-linear slope was evident for wheat, rye and amaranth dough in the range of lower frequencies (0.01–0.10 Hz).

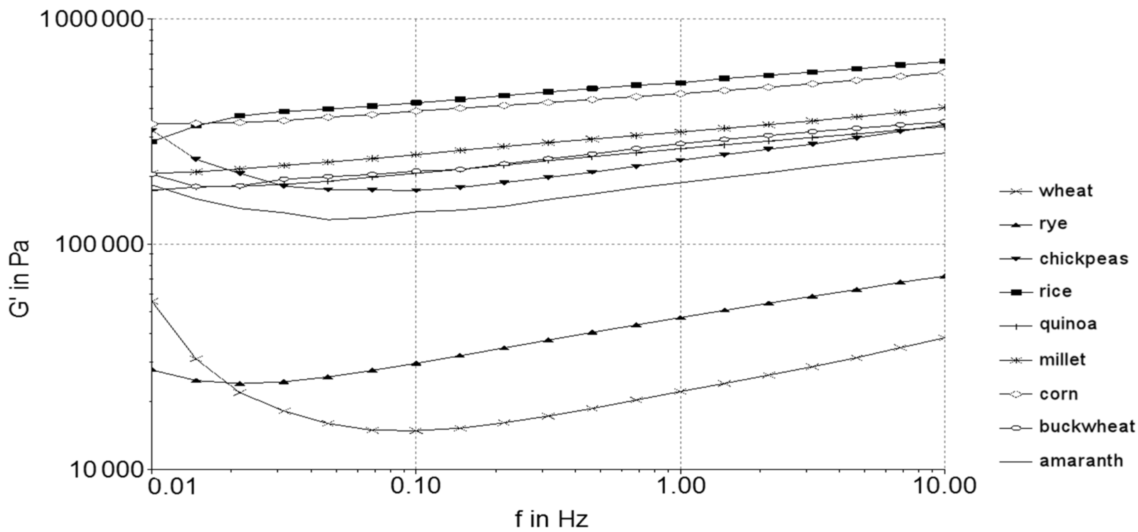

Figure 1 Mechanical spectra of storage modulus G´ for gluten-free and control wheat and rye dough

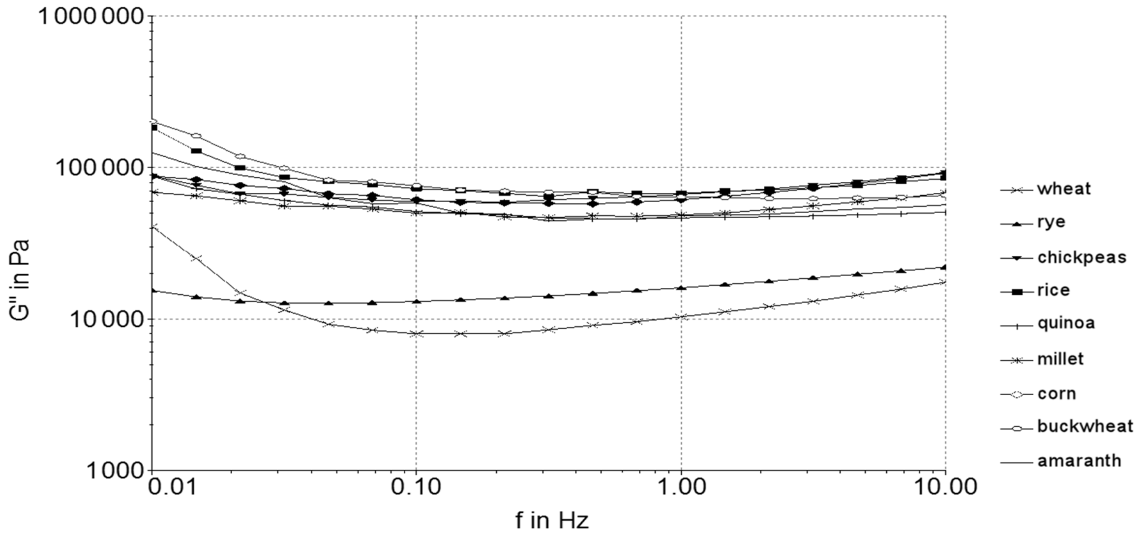

Figure 2 Mechanical spectra of loss modulus G´´ for gluten-free and control wheat and rye dough

Values of phase angle tg(δ) did not reach unit (Fig. 3) in the range of investigated frequencies (0.01–10.00 Hz). Values decreased with increasing frequency. Quite different trend was recorded for chickpea dough; higher G´and G´´ and lower tg(δ) in frequencies 0.01–0.04 Hz could be attributed to the inadequate dough hydratation. Values of tg(δ) recorded for wheat and rye dough were greater in frequencies 0.10–10.00 Hz. Greater values of tg(δ) are typical for dough with relatively higher proportion of viscous characteristics compared to elastic ones (**Khatkar *et al.***, 1995). The increase of relative proportion of viscous characteristics was found for all of investigated dough in lower, 0.01–0.10 Hz frequencies. Lower values of tg(δ), typical for elastic and firm dough (**Cosgrove *et al.*, 2005**), were recorded for rice and corn dough (0.12–0.25). Values of tg(δ) measured in frequencies 1.0–10.0 Hz were published only for rice dough (**Moreira *et al.*, 2013b**) and our results are consistent with published values. The agreement between our results and published values (**Lamacchia *et al.*, 2010**) was found for storage and loss moduli recorded for amaranth and quinoa dough as well.

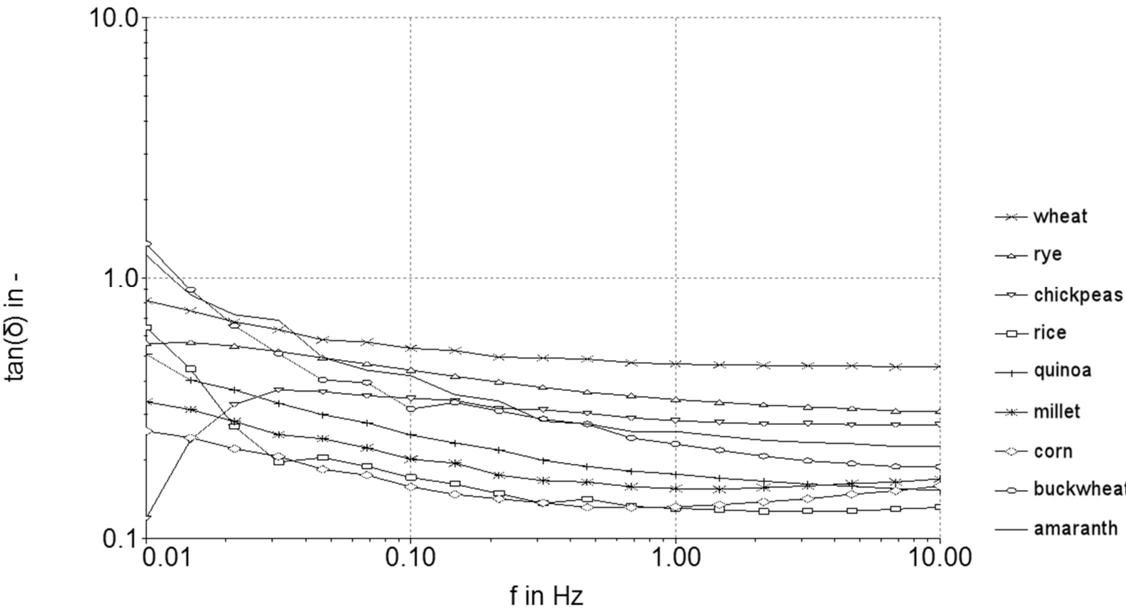

Figure 3 Mechanical spectra of phase angle tg(δ) for gluten-free and control wheat and rye dough

Bread with the highest volume (432 ml) was prepared from wheat flour (Table 1). Gluten-free breads with higher volumes were prepared from buckwheat (313 ml), quinoa (287 ml), amaranth (270 ml) and chickpea (250 ml) flour. The volumes of these gluten-free breads were significantly lower than volume of wheat bread but larger than rye bread volume. The volumes of millet (190 ml), corn (198 ml) and rice (210 ml) bread were nearly equal to the volume of rye bread.

Table 1 Mean values of gluten-free bread volume (ml)

Flour	Volume
Amaranth	$270{\pm}10^{d}$
Chickpea	$250{\pm}10^{c}$
Millet	$190{\pm}10^{a}$
Corn	$198{\pm}6^{ab}$
Quinoa	$287{\pm}8^{d}$
Buckwheat	$313{\pm}8^{e}$
Rice	$210{\pm}3^{b}$
Wheat	$432{\pm}3^{f}$
Rye	$202{\pm}9^{ab}$

Legend: Means with different letters within a column are significantly different ($P < 0.01$)

The bread volume was in significant correlation with storage modulus G´ in the whole range of frequencies and in significant correlation with phase angle in 0.02–0.10 Hz frequencies (Table 2). Based on values of storage modulus and phase angle it can be concluded the bread with lower volume was prepared from firmer dough with greater values of storage modulus G´. Contrary, the bread with larger volume was prepared from less firm dough (buckwheat, quinoa and amaranth) with lower values of storage modulus G´ and higher values of phase angle in lower frequencies in range 0.01–0.10 Hz.

CONCLUSION

The results of study indicated applicability of dynamic oscillation rheometry in the range of frequencies 0.01–10.00 for testing bread-making quality of gluten-free dough. Bread-making quality can be described by storage modulus G´and phase angle tg(δ). Bread with larger volume was prepared form dough with non-linear slope of storage modulus G´ and phase angle in the range of lower frequencies 0.01–0.10 Hz.

Table 2 Frequency dependence of values of correlation coefficients between moduli, tg(δ) and bread volume.

Frequency (Hz)	G´	G´´	tg(δ)
0.010	-0.83	NS	0.56
0.015	-0.92	NS	0.78
0.026	-0.88	NS	0.84
0.032	-0.82	NS	0.81
0.046	-0.83	NS	0.78
0.068	-0.82	NS	0.74
0.100	-0.81	NS	0.70
0.147	-0.81	NS	0.72
0.215	-0.80	NS	0.67
0.316	-0.79	NS	0.70
0.464	-0.79	NS	0.63
0.681	-0.79	NS	0.61
1.000	-0.79	NS	NS
1.468	-0.79	-0.62	NS
2.154	-0.80	-0.70	NS
3.162	-0.80	-0.74	NS
4.646	-0.81	-0.79	NS
6.813	-0.84	-0.83	NS
10.000	-0.82	-0.82	NS

Legend: $P < 0.05$; NS = non significant

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