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Rheological properties of wheat flour substitutes/alternative crops assessed by Mixolab

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Abstract

Wheat is one of the most common cereals used in the world. However, due to greater public awareness of celiac disease and gluten intolerance as well as consumers demands for healthy food and variety in food products, in many widely consumed staples, such as bread, wheat flour is fully or partially replaced with flour from other cereals, pseudocereals or legumes. Although wheat flour alternatives are readily available in the market, these products are often of inferior quality. The aim of this paper was to predict the suitability of alternative crops such as rice, corn, buckwheat, amaranth and soya for the production of quality bread. Their rheological properties were studied, and compared to the properties of wheat flour which served as a benchmark. The tested alternative cereals, pseudocereals and legumes were selected in order to represent the widely used ones in gluten-free products as well as the ones found to be nutritionally improved according to recent publications. Moreover, the differences between wheat and buckwheat flour, and their wholegrain counterparts were also studied. The determination of rheological properties of wheat flour dough as well as the dough from other raw materials (rice, corn, buckwheat, amaranth and soya) was performed by Mixolab. According to results obtained by Mixolab measurements, flours from different raw materials exhibited Mixolab profiles which greatly differ from wheat flour profile. Samples of rice and both types of buckwheat flour expressed the most similar rheological behaviour to wheat flour. However, since, there was no tested material which exactly mimic wheat flour dough properties, it was concluded that their mixtures would give the optimal rheological profile. Although it is a very challenging task to mimic wheat flour unique breadmaking properties, it is possible to create products having similar rheological behaviour to wheat flour dough, but improved functional properties.

Keywords: gluten-free flours; Mixolab; rheology; wheat flour alternatives

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1. Introduction

Wheat is one of the most common cereals used for breadmaking. However, bread prepared from wheat flour dough is considered to be nutritionally poor [1].

Partial replacement of wheat flour with non-wheat flours improves the nutritional quality of bakery products and satisfies consumers' demands for healthy food and variety in food products. Moreover, in recent years there has been increasing interest in replacing common gluten-free formulations made from refined gluten-free flour, starch and hydrocolloids with those enriched with functional gluten-free ingredients [2, 3]. Namely, application of pseudocereals such as amaranth, quinoa and buckwheat resulted in gluten-free breads with an increased content of important nutrients such as protein, fiber, calcium, iron, vitamin E and polyphenols [2]. Also, according to Sabanis & Tzia and Traynham et al. [1, 3] soybean flour can compensate for the lysine and other biologically active components (isoflavones) deficiency of wheat flour.

On the other hand, in many countries where wheat is not a major domestic crop, substitution of the wheat flour with flours from other cereal grains such as corn and rice is done due to economic reasons [4, 5]. Except being the second most widely produced cereal crop, corn flour contains high levels of many important vitamins and minerals [6]. Similarly, rice is a staple food for more than half of world population [7]. It is also characterize with bland taste, white colour, ease of digestion, and hypoallergenic properties [8].

However, substitution of wheat flour with flours from other raw materials will alter rheological properties of dough, as well as the quality of baked product. It is well known that proteins encountered in non-wheat flours lack the ability to form the gluten network responsible for holding the gas produced during the fermentation [9, 10].

Among different rheological techniques, Mixolab has been likely used in many studies for probing dough behavior during processing conditions [11, 12, 13]. By using Mixolab it is possible to record the mechanical changes due to mixing and heating simulating the mechanical work as well as the heat conditions that might be expected during the bread making and bread baking processes. The advantage of using Mixolab is that in a single test one can measure properties of proteins and starch (and associated enzymes).

The suitability of alternative crops for the production of quality bread is mainly examined by measuring the properties of their blends with wheat or some other flour. On contrary, the aim of this paper was to determine the behaviour of pure non-wheat flours obtained from rice, corn, buckwheat, amaranth and soybean, during mixing and heating by using Mixolab. Their rheological properties were compared to the properties of wheat flour which served as a benchmark. The tested alternative cereals, pseudocereals and legumes were selected in order to represent the widely used ones in gluten-free products as well as the ones found to be nutritionally improved according to recent publications. Moreover, the differences between wheat and buckwheat flour, and their wholegrain counterparts were also studied.

2. Materials & Methods

2.1. Materials

Wheat flour, wholegrain wheat flour, rice flour, corn flour, buckwheat flour, wholegrain buckwheat flour, amaranth flour and soybean flour were purchased from local market. The proximate composition of the flour samples is given in Table 1. Moisture and ash content were determined following the ICC methods No 110/1 and 104/1, respectively (ICC, 1996). Kjeldahl method was used to characterize the protein content. Fat and starch were given by Weibull-Stoldt and Ewers methods, respectively.

Table 1. Chemical composition of raw materials[(a,b)] (%)

Flour type	Wheat flour	Wholegrain wheat flour	Buckwheat flour	Wholegrain buckwheat flour	Amaranth flour	Rice flour	Corn flour	Soybean flour
Moisture	13.10[f]	13.60[g]	10.10[e]	9.76[d]	6.14[a]	9.09[c]	10.02[de]	7.50[b]
Protein[(c)]	11.40[c]	13.00[d]	8.34[b]	13.40[d]	16.30[e]	8.04[b]	6.74[a]	47.60[f]
Fat[(c)]	0.75[b]	2.34[d]	1.95[c]	3.08[f]	5.80[g]	0.33[a]	2.45[e]	6.90[h]
Starch[(c)]	71.30[e]	66.80[b]	68.20[d]	67.40[d]	64.30[c]	81.50[g]	79.20[f]	6.08[a]
Ash[(c)]	0.47[b]	1.14[e]	0.98[d]	1.97[f]	2.40[g]	0.26[a]	0.68[c]	6.60[h]

[(a)]Values are expressed as means (n = 3)
[(b)]Values in the same row followed by different letters are significantly different ($p < 0.05$)
[(c)]Dry matter basis

2.2. Mixolab measurements

Rheological behaviour of different raw materials was determined by Chopin Mixolab, Villeneuve-la-Garenne, France**,** using the ICC method No 173 and Chopin+ protocol with the slight modification in dough weight from 75 g to 90 g. The typical Mixolab curve, showing the following parameters: **water absorption** (%) – WA or the percentage of water required for the dough to produce a torque of 1.1; **dough development time** (min) – DDT or the time to reach the maximum torque at 30 °C; **stability** (min) or time until the loss of consistency is lower than 11% of the maximum consistency reached during the mixing,; **initial maximum consistency** (Nm) - C1, used to determine the water absorption; **torque at the end of the holding time at 30 °C** (Nm) – C1.2; **mechanical weakening** (Nm) - the torque difference between C1 and C1.2; **minimum consistency** (Nm) - C2, the minimum value of torque produced by dough passage while being subjected to mechanical and thermal constraints; **thermal weakening** (Nm) - the difference between the C1.2 and C2 torques; **pasting temperature** (° C) – the temperature at the onset of this rise in viscosity; **peak torque** (Nm) - C3, the maximum torque produced during the heating stage; **peak temperature** (° C) – the temperature at the peak viscosity; **minimum torque** (Nm) – C4, minimum torque reached during cooling to 50°C; **breakdown torque** (Nm) – calculated as the difference between C3 and C4; **final torque** (Nm) – C5, the torque after cooling at 50°C; **setback torque** (Nm) - the difference between C5 and C4 torque, is illustrated in Figure 1. In addition, the angles between ascending and descending curves α, β and γ (Nm/min) were calculated and defined as protein network weakening, gelatinization and cooking stability rate, respectively.

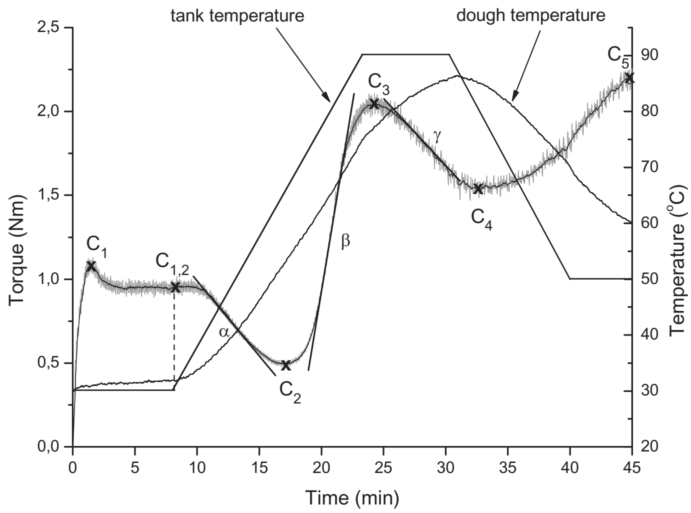

Fig. 1. Mixolab profile

3. Results & Discussion

The wheat and non-wheat flours were characterized in terms of protein quality and thermo-mechanical behaviour by using Mixolab device. Main derived parameters from the Mixolab curves are presented in Table 2.

Water absorption, dough development time, stability and mechanical weakening are parameters which refer to dough characteristics during mixing at constant temperature, 30°C, describing the dough behavior during processing stage. During mixing hydration of the compounds and the stretching and alignment of the proteins occurs, which lead to the formation of a three-dimensional viscoelastic structure [14]. Wheat flour dough, which served as a control sample was characterized with low DDT, long stability and great resistance to mechanical constrain. These properties of wheat flour are related to its unique protein composition and quality. Namely, as it is already known, wheat proteins are mainly consisted of gluten proteins (approximately about 80-85% of total wheat protein) which comprise of prolamins (in wheat - gliadins) and glutelins (in wheat - glutenins). In contrast, non gluten proteins (albumins and globulins) are presented in 15-20% of the total wheat proteins [15, 16]. Wheat storage protein (gluten) is a viscoelastic protein responsible for dough structure formation [17].

The wholegrain wheat flour, which, due to the presence of bran fraction (seed coat and embryo), has higher levels of non storage proteins and fat (Table 1), was characterize with higher WA and DDT, and lower stability. The high hydration capacity of the wholemeal flour was reported earlier [18] and ascribed to the presence of water absorbing arabinoxylans.

Rice flour and buckwheat flour had similar water absorption values as the wheat flour. Moreover, these flours developed dough which resembles wheat flour dough in ability to resist the deformation for longer time. Therefore, the combination of these flours has found significant application in gluten-free product development [19]. All the other non wheat flours (wholegrain buckwheat, amaranthus, corn and soybean) had significantly higher WA and lower stability. However, rice flour and buckwheat flour had significantly higher DDT, indicating that these flours need longer time to hydrate all the compounds than wheat flour. Namely, as it is presented in Table 1, rice and buckwheat flour have considerably lower protein content compared with wheat flour. Moreover, rice flour proteins are mainly consisted of glutelins (65-85%) and only small amount of prolamins (2.5 - 3.5%) is present [20], while the proteins in pseudocerals, such as buckwheat and amaranth, are composed mainly of globulins and albumins [2].

Concerning the DDT the soybean flour expressed the most similar value to wheat flour. Namely, soybean is possibly the richest food in proteins, as it can be seen in Table 1. However, soybean flour required considerably larger amount of water (101.4% WA) to achieve a torque of 1.1 Nm, compared to wheat (60.0% WA) flour. Higher absorption, lower dough development time and higher mechanical weakening in comparison to wheat flour were also observed for amaranth flour, which is in accordance to results reported by Lorenz [21].

Table 2. Mixolab parameters of different flours[(a,b)]

Flour Type[(c)]	WF	WWF	BF	WBF	AF	RF	CF	SF
Water absorption (%)	60.0[b]	63.9[d]	58.1[a]	67.6[e]	71.5[f]	60.9[c]	63.6[d]	101.4[g]
Dough development time (min)	1.43[c]	8.00[g]	6.63[f]	5.93[e]	0.50[a]	8.77[h]	4.37[d]	0.78[b]
Stability (min)	11.18[e]	7.78[c]	10.97[e]	5.67[b]	0.52[a]	12.22[f]	7.23[c]	9.45[d]
C1.2	1.1[d]	1.1[d]	1.09[d]	1.02[bc]	0.42[a]	1.1[d]	1.05[c]	0.99[b]
Mechanical weakening (Nm)	0[a]	0[a]	0.01[a]	0.08[c]	0.68[e]	0[a]	0.05[b]	0.11[d]
C2 (Nm)	0.55[d]	0.40[b]	0.49[c]	0.39[b]	0.17[a]	0.84[e]	0.57[d]	0.49[c]
Thermal weakening (Nm)	0.55[c]	0.7[e]	0.6[d]	0.63[d]	0.25[a]	0.26[a]	0.48[b]	0.50[b]
C3 (Nm)	2.35[e]	2.30[e]	1.86[d]	1.32[c]	0.28[a]	2.80[g]	2.59[f]	0.78[b]
Pasting temperature (° C)	53.9[b]	55.9[c]	59.2[e]	56.6[c]	60.2[e]	50.4[a]	57.9[d]	72.4[f]
Peak temperature (° C)	77.9[b]	76.9[a]	85.7[f]	76.3[a]	80.4[e]	77.9[b]	79.4[c]	79.0[c]
C4 (Nm)	2.01[e]	1.56[d]	1.82[e]	1.15[c]	0.28[a]	2.55[g]	2.38[f]	0.74[b]
Breakdown torque (Nm)	0.34[e]	0.74[f]	0.04[b]	0.17[c]	0[a]	0.25[d]	0.21[cd]	0.04[b]
C5 (Nm)	2.75[e]	2.36[d]	2.59[de]	1.64[c]	0.39[a]	3.19[f]	3.36[g]	0.94[b]
Setback torque (Nm)	0.74[e]	0.80[f]	0.77[e]	0.49[c]	0.11[a]	0.64[d]	0.98[g]	0.20[b]
α (Nm/min)	0.038[f]	-0.090[a]	-0.084[b]	-0.048[c]	-0.024[d]	-0.026[d]	-0.046[c]	-0.020[e]
β (Nm/min)	0.692[e]	0.980[g]	0.288[b]	0.358[c]	0.022[a]	0.478[d]	0.838[f]	0.024[a]
γ (Nm/min)	-0.050[d]	-0.090[a]	-0.004[f]	-0.046[d]	0[g]	-0.056[c]	-0.028[e]	-0.062[b]

[(a)]Values are expressed as means (n = 2)

[(b)]Values in the same row followed by different letters are significantly different ($p < 0.05$)

[(c)] WF – Wheat flour, WWF – Wholegrain wheat flour, BF – Buckwheat flour, WBF – Wholegrain buckwheat flour, AF – Amaranth flour, RF – Rice flour, CF – Corn flour, SF – Soybean flour

On heating, aggregation and denaturation of the proteins occurs [22], which result in a decrease in dough consistency (C2 value). Rice flour proteins expressed the lower weakening due to mechanical and thermal constrains, while the amaranth flour were characterize with higher protein reduction and thus the lower protein quality.

As heating proceeded, protein changes have minor influence and the starch granules have predominant role in torque increase [11]. The increase in viscosity and thus in the torque is the result of the starch granules swelling due to the water uptake and amylose chains leaching into the aqueous intergranular phase [23]. Wheat flour contributed to a better starch performance of the samples (higher starch gelatinization, C3) than wholegrain, pseudocereal and soybean flours. This could be ascribed to the competence for water established between the starch and the bran present in the wholegrain and pseudocereal flours [12]. The lower maximum peak, as well as the lower gelatinization rate (β), was expressed by amaranth and soybean flour which had lower starch content and higher lipid content than other raw materials (Table 1). The obtained results were in agreement with the finding that lipids form complex with amylose that results in lowering peak viscosity [24]. On contrary, rice and corn flour, which are rich in carbohydrates (Table 1), had higher maximum peak torques and gelatinization rates than other flours.

The further reduction in viscosity (C4 value) is the result of the physical breakdown of the granules due to the mechanical shear stress and the temperature constraint [11]. Breakdown torque (C3-C4) is also a measure of amylase activity. Namely, the greater the difference between C3 and C4 is, the greater the amylase activity is. Subsequently, on cooling, starch retrogrades and the consistency increases (C5 value) [12]. According to the results summarized in Table 2, flours obtained from pseudocereals (buckwheat and amaranth) exhibited the lowest breakdown torques and cooking stability rates. Namely, Ikeda et al. [25] proved that buckwheat seed contains an α-amylase inhibitor which resulted in lower C3-C4 values. Since cooking stabilities could be related with extended shelf life of bread [12], it can be concluded that breads containing pseudoceral flours would express slower increase in bread firming during storage. Moreover, amaranth flour had the lowest final (C5) and setback torque (C5-C4), and thus the lowest starch retrogradation.

4. Conclusion

Flours from different raw materials were tested in order to investigate their ability to mimic wheat flour dough behaviour during bread making and bread baking. Among tested alternative cereals (rice, corn), pseudocereals (buckwheat, amaranth) and legumes (soybean), rice and buckwheat flours expressed the most similar protein (water absorptions, stabilities and degrees of mechanical weakening) and starch (peak, minimum and setback torque) characteristics as wheat flour. Since Mixolab profile of wheat flour was located between rice and buckwheat flour profiles, it can be concluded that blends of rice and buckwheat flours would give the optimal rheological profile.

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