RHEOLOGICAL PROPERTIES OF WHOLE GRAIN WHEAT, RYE AND HULL-LESS BARLEY FLOUR BLENDS FOR PASTA PRODUCTION

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Abstract
Whole grain flour can be considered as a good candidate for pasta fortification due to the health benefits. Literature reports pasta dough fortification with non-traditional ingredients and cereals. Therefore, the purpose of the current research was to investigate rheological properties of whole grain flour blends for pasta production. Flour blends were made from wheat flour (type 405) in a combination with other flours (whole grain wheat, rye or hull-less barley flour) in various proportions (from 10% to 50%). Wheat flour type 405 was used as a control. Rheological properties of dough were analysed using Farinograph AT (Brabender, GmbH&Co.KG., Germany) and starch gelatinization properties of flour starch using Amylograph-E (Brabender GmbH&Co.KG., Germany); moisture content of flour samples (AACC 44-15A from 2000). The results of present research demonstrate that rheological properties of dough decrease if the amount of whole grain flour in blend increases. It was concluded that water absorption and dough development time of dough with whole grain flour blends addition is less than the parameters of control wheat flour (type 405). However, a higher starch gelatinization was obtained for flour blends with whole wheat grain flour, comparing to blends with whole rye and hull-less barley grain flour, which mainly could be explained with a higher gluten content of whole wheat grain flour.
Key words: whole grain, flour blends, pasta, farinograph, amylograph.

Introduction

Cereal-based foods have been staples for humans for millennia. Cereal grains contain the macronutrients (carbohydrate, protein and fat) required by humans for growth and maintenance. They also supply important minerals, vitamins and other micronutrients essential for optimal human health conditions (Topping, 2007).

Traditionally, pasta products are made from wheat semolina, although more recently other cereals have been used to partially replace it (Chillo et al., 2008, Manthey et al., 2004 and Petitot et al., 2010). Common wheat flour also can be useful for precooked pasta products, but because of the low protein content, addition of high protein components such as whole grain flour may enrich the products and result in improved functional properties and quality when the right processing conditions are used (Chillo et al., 2008). Wheat (*Triticum spp.*) is the main cereal crop used for human consumption in many areas of the world. Traditionally, pasta is manufactured from durum wheat (*Triticum durum* D.) with protein <15%, which results in a product considered to be of superior quality to pasta made from cheaper common wheat (*Triticum aestivum* L.) or a blend of the two species (Sissons et al., 2005; Troccoli et al., 2000). Rye (*Secale cereale*) could be exploited more efficiently in new types of pasta products due to its positive health effects. Nowadays, its use is limited mainly as a result of the problems arising from its pentosan and water-soluble proteins. Hull-less barley (*Hordeum vulgare* L.) has been intensively investigated in respect to its food, feed and industrial applications. The advantage of hull-less barley compared to hulled barley in food uses is that pearling is not needed, so that the outer part of the endosperm, the aleurone, which contains proteins with essential amino acids and vitamins, is retained, as well as other bioactive compounds (Andersson et al., 2004).

Characterization of rheological properties of dough is effective in predicting the processing behaviour and in controlling the quality of food products (Song and Zheng, 2007). When wheat flour is mixed with water, with the required amount of energy, dough is formed. The behaviour of the resulting dough when submitted to mechanical energy input is determined by dough rheological properties (Bloksma, 1990). The Farinograph results reveal dough-mixing properties which are ascribed to wheat gluten, starch, lipid and water contents, as well as the amount and activity of α-amylase.

Gliadin and glutenin are the two primary types of grain protein which are responsible for the elastic and viscous properties, respectively, which help to form a continuous spatial network in the dough (Koehler et al., 2010). These properties derive largely from the gluten proteins, which form a continuous viscoelastic network within the dough. Gliadins are monomeric proteins that form only intra-molecular disulphide bonds, if present; whereas glutenins are polymeric proteins whose subunits are held together by inter-molecular disulphide bonds, although intra-chain bonds are also present. Among these proteins, glutenins (polymeric proteins) have been shown to be extremely important in determining rheological properties (Jia et al., 1996). Gluten proteins are susceptible to heat treatment and their behaviours subjected to relatively high temperatures (Weegels et al., 1994). Gluten is the main base of the wheat dough and is the protein that only exists in wheat and rye. Wheat flour dough simultaneously exhibit characteristics of a viscous liquid and of an elastic solid and hence are classed as viscoelastic materials (Bagley et al., 1998). At the macromolecular level, pasta is essentially a large protein network formed by irreversible protein–protein crosslinks through thermal dehydration, which encapsulates starch granules (Drawe, 2001). Dough mechanical properties depend on a large variety of factors including flour mixing time, etc. (Bagley et al., 1998). Bran and germ particles also disrupt the continuity of the protein network, resulting in weaker, less firm pasta (Manthey and Schorno, 2002).

The Amylograph results reveal starch properties which are ascribed to grain. Starch generally consists of two D-glucose homopolymers, the linear polymer amylose and a highly branched glucan amylopectin that connects linear chains. Starch granules contain an amylose and amylopectin. Amylopectin structurally contributes to the crystalline organization of the starch granule in cereals. Amylopectin chain length distribution also affects gelatinization, retrogradation, and pasting properties of starch (Jeon et al., 2010). Starch gelatinization is a process that breaks down the intermolecular bonds of starch molecules in the presence of water and heat, allowing the hydrogen bonding sites (the hydroxyl hydrogen and oxygen) to engage more water (Sobkowska, 2001). Starch is essential to determine the pasta cooking quality (Delcour et al., 2000). Starch affects the water absorbency, gel consistency and integrity of the gluten matrix during cooking (Edwards et al., 1999). Bran from whole grain flour can interfere with water migration during this step, increasing water retention within the pasta (Villeneuve and Gélinas, 2007).

In the scientific literature it is reported, that when pasta dough is fortified with non-traditional ingredients, it behaves differently. Therefore, the purpose of the current research was to investigate rheological properties of whole wheat, rye and hull-less barley flour blends for pasta production.

Materials and Methods

The study was carried out at the scientific laboratories of Faculty of Food Technology at Latvia University of Agriculture (LLU) and at the laboratory of the JSC "Jelgavas dzirnavas" (Latvia).

Conventional rye (′Kaupo′) and hull-less barley (line ′PR 5099′) grains of 2014 cultivated at State Priekuli Plant Breeding Institute (Latvia), wheat (′Zentos′) grain cultivated at LLU research center „Peterlauki" (Latvia) were used in the experiments. For the flour blend obtaining wheat flour type 405 from JSC "Dobeles dzirnavnieks" (Latvia) was used. Rye, wheat and hull-less grain were ground in the laboratory mill PLM3100/B (Perten, Sweden) obtaining fine whole grain flour. Wheat flour type 405 was used as a control. Blends were made from whole rye, hull-less barley or wheat flour in combination with wheat flour (type 405) in various proportions. As a result, fifteen several flour blends were developed: flour blend with whole rye or hull-less barley, or wheat flour. Experimentally, a part of wheat flour type 405 was replaced with whole grain flour from 10% to 50% (Table 1).

Table 1

Sample composition per 100% of flour blend

Sample code	405 type wheat flour, %	Whole grain flour type		
		Rye, %	Wheat, %	Hull-less barley, %
100% W	100	–	–	–
10% WR	90	10	–	–
10% WW	90	–	10	–
10% WH	90	–	–	10
20% WR	80	20	–	–
20% WW	80	–	20	–
20% WH	80	–	–	20
30% WR	70	30	–	–
30% WW	70	–	30	–
30% WH	70	–	–	30
40% WR	60	40	–	–
40% WW	60	–	40	–
40% WH	60	–	–	40
50% WR	50	50	–	–
50% WW	50	–	50	–
50% WH	50	–	–	50

Moisture content of flour samples was determined using air-oven method (AACC 44-15A from 2000).

For analysis of rheological properties Farinograph-AT (Brabender GmbH&Co.KG., Germany) was used according to the international standard method (AACC No. 54-21, ICC No. 115/1). For all samples the following parameters were determined: water absorption (WA) of flour and flour blends, stability of dough (S), development time of dough (DDT), and the degree of softening (DS).

For analysis of starch gelatinization properties Amylograph-E (Brabender GmbH&Co.KG., Germany) was used according to the international standard method (AACC standard 22-10; ICC No. 126/1). The acquired diagram was evaluated for the gelatinization maximum and the gelatinization temperature (ICC Standard 126/1, 1992).

Microsoft Excel software was used for the research purpose to calculate mean values and standard deviations of the obtained data. SPSS 20.0 software was used to determine the significance of research results, which were analysed using the two-factor ANOVA analyses to explore the impact of factors and their interaction, and the significance effect ($p<0.05$). Analysis was realised in triplicate.

Results and Discussion

Moisture content of flour used in the research was from 10.23% (whole wheat) to 14.16% (wheat flour), but in flour blend samples – from 12.20% to 13.79%. In the present experiments a significantly higher ($p<0.05$) moisture content was obtained for wheat flour type 405, comparing with whole grain flour and flour blend samples.

Water absorption (WA) is a parameter indicated as the amount of water needed to develop the standard dough of 500 farinograph unit (FU) at the peak of the curve. Stronger wheat flours have the ability to absorb and retain more water as compared to weak flours (Mis, 2005). In the present experiment it was observed that water absorption of analysed flour sample increases by adding whole grain flour (Figure 1).

At the same time, the smaller water absorption was obtained for the control wheat flour sample (59.1 ± 0.2%), while significantly higher ($p<0.05$) – for whole rye grain flour (71.5 ± 0.2%). Present results demonstrate that the value of water absorption for whole wheat or hull-less barley increases by ~ 2%, but for whole rye by ~ 4%. Obtained results could be explained with lower moisture content and higher bran content of analysed whole grain flour. However, the inclusion of a higher amount of bran in the dough formulation usually resulted in increased dough water absorption due to the higher levels of pentosans present in bran (Sanz-Penella et al. 2008). Besides, bran from whole grain flour can interfere with water migration during this step, increasing water retention within the pasta (Villeneuve and Gélinas, 2007).

Gluten has viscoelastic behaviour in which gliadin and glutenin fractions represent viscous and elastic behaviour, respectively. Both quality and quantity of gluten proteins affect the flour processing quality. The gluten in the manufacture of pasta has two main functions: providing dough plasticity linking all the components which are fed through the binder matrix

Table 2

Moisture content in flours and flour blend samples

No.	Samples	Moisture, %
1.	Flour blend with 10% whole rye	13.79
2.	Flour blend with 10% whole wheat	13.78
3.	Flour blend with 10% whole hull-less barley	13.77
4.	Flour blend with 20% whole rye	13.42
5.	Flour blend with 20% whole wheat	13.40
6.	Flour blend with 20% whole hull-less barley	13.37
7.	Flour blend with 30% whole rye	13.05
8.	Flour blend with 30% whole wheat	13.03
9.	Flour blend with 30% whole hull-less barley	12.98
10.	Flour blend with 40% whole rye	12.68
11.	Flour blend with 40% whole wheat	12.65
12.	Flour blend with 40% whole hull-less barley	12.59
13.	Flour blend with 50% whole rye	12.31
14.	Flour blend with 50% whole wheat	12.27
15.	Flour blend with 50% whole hull-less barley	12.20

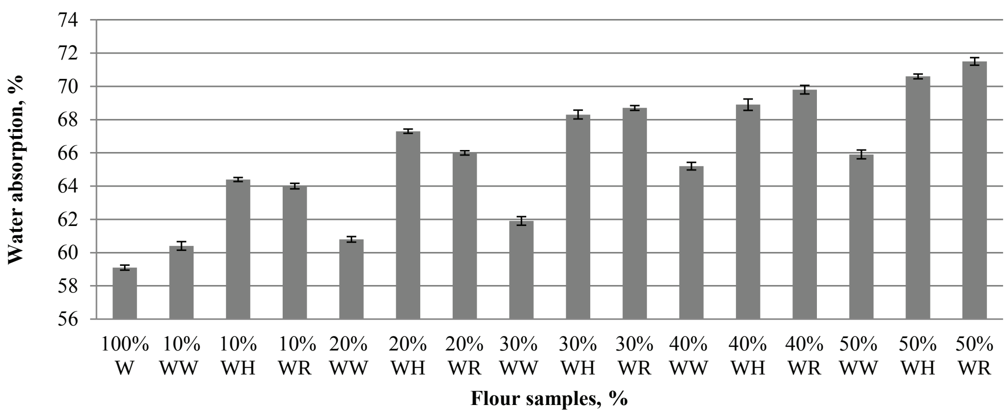

Figure 1. Water absorption for flour blend samples.

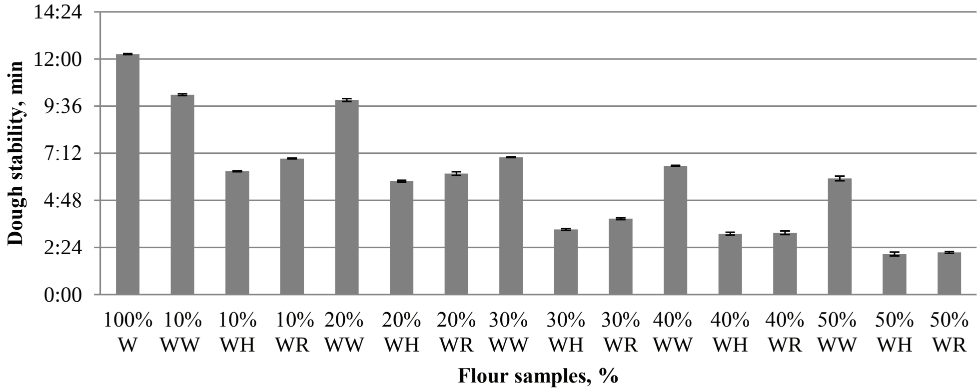

Figure 2. Dough stability for flour blend samples.

and starch grains in one mass to keep a form extruder matrix. Gluten is unique for pasta production, because it keeps the gluten matrix in starch granules (Осипова, 2009).

Pasta structure is as a compact matrix of protein network formation and starch granules (Cunin et al., 1995). As a result, the gluten structure is responsible for the nutritional characteristics of pasta and the formation of various technological stages (Scanlo n et al., 2005). Variation in protein content alone is not responsible for the differences in dough properties and suitability for end-products amongst the cultivars (Zhu and Khan, 2002). However, dough stability (DS) is as the time difference between the point where the top of the curve first intercepts the 500 FU line and the point where the top of the curve leaves the 500 FU line. Dough stability indicates the time when the dough maintains maximum consistency and is a good indication of dough strength. Good wheat quality dough has stability of 4–12 min (Kulhomäki and Salovaara, 1985). Stability time of control wheat dough sample was 12:15min. However, dough stability time decreases by increasing of whole grain wheat, rye and hull-less barley flour (Figure 2) additive.

Bran and germ particles also disrupt the continuity of the protein network, resulting in weaker, less firm pasta (Manthey and Schorno, 2002). Such changes could mainly be explained with possible decreases of gluten content in the analysed whole grain flour samples. Short dough stability time mainly could indicate non-acceptable dough properties during kneading and formation of pasta. There dough stability time less than 4 min could be non-acceptable. As a result, the obtained products as, for example, pasta could be with non-acceptable quality properties. Therefore, for obtaining of dough with good properties, the additive of whole rye and whole hull-less barley grain flour could be 20%, but of whole wheat grain flour – 50%.

Wheat flour (control) showed the lowest dough development time (DDT) (2:22 min), but the higher development time (3:36 min) was obtained for whole wheat grain flour, for whole rye grain flour (6:36 min) and for whole hull-less barley grain flour (6:52 min) (Figure 3). Increased dough development time could mainly be explained with differences in chemical composition of whole grain flour, as elevated dietary fiber content, especially, and, possibly, more proteins.

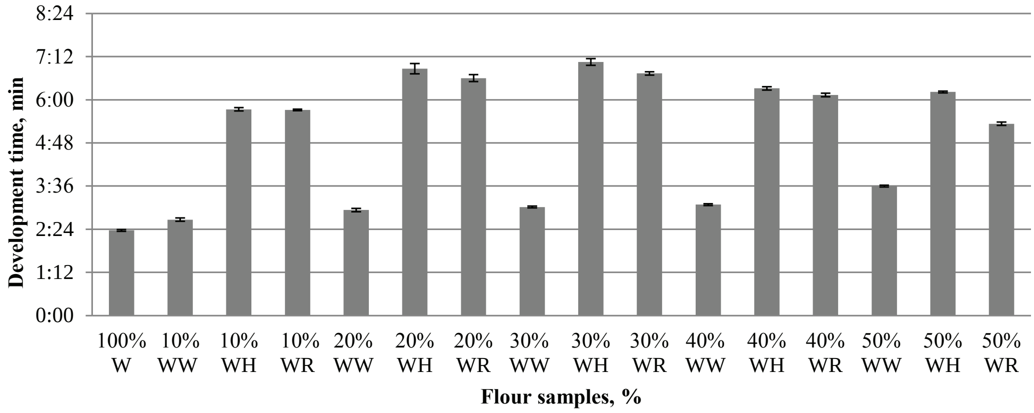

Figure 3. Development time for flour blend samples.

Table 3

Starch gelatization parameters of flour blends

Flour blend samples	Beginning of gelatinization, °C	Gelatinization, °C	Gelatinization maximum, AU
Wheat flour	60.3*	85.4*	1100*
Flour blend with 50% whole wheat	61.8**	90.9**	1095*
Flour blend with 20% whole rye	60,3*	85.3*	1097*
Flour blend with 20% whole hull-less barley	59.9*	85.7*	1100*

* – there is no significant difference between samples (p>0.05);
** – there are significant differences between samples (p<0.05).

Similar results were found in the *Zhang 2014,* as the dough development time for waxy wheat flour (1.5 min) was shorter than that of wheat flour (2.1 min) - an advantage for improving output during the actual production. The results of the pasta dough rheological properties demonstrate that of wholemeal flour amount to be added whole grain wheat flour – 50%, whole grain rye and hull-less barley – 20%.

To ensure high-quality pasta production already in the raw materials it is necessary to ensure a high protein content and quality, good starch properties (Cubadda et al., 2007; Delcour et al., 2000). Gelatinization process occurs at 62.5 °C, when the amount of water absorbed by the starch granules is 4–5 times for obtaining of a viscous fluid (Осипова, 2009). Starch is essential to determine the pasta cooking quality (Delcour et al., 2000). During pasta cooking, protein existing network restricts the diffusion of water and limits the swelling of starch granules in the central zone of pasta. The extrusion process causes damage to the protein matrix; the resulting pasta is compact and a continuous protein network (Stefano and Marco, 2009). Starch gelatization temperature is very important for the development of pasta technological production parameters, especially extrusion temperature. Therefore (Table 3), the determination of starch gelatization temperature of obtained flour blends with chosen rheological parameters (80% wheat type 405 + 20% whole hull-less barley; 80% wheat type 405 + 20% whole rye; 50% wheat type 405 + 50% whole wheat and 100% wheat type 405 flour) was recommendable.

In the present experiments a significantly higher (p<0.05) was obtained for wheat flour type 405, comparing with whole wheat, whole rye and whole hull-less barley grain flour. Obtained results demonstrate that a higher gelatinization temperature (90.9 °C) was for whole wheat grain flour, lower – for whole rye grain flour (85.3 °C). The higher gelatinization temperature demonstrates a higher thermal stability in the future processing (Marti et al., 2010). Wheat starch gelatinization temperature at around 52–85 °C and processing by heating the dough to 80–90 °C in a presence of water is sufficient to initiate starch swelling and gelatinization (Thomas and Atwell, 1999).

Conclusions

1. In the present experiment it was demonstrated that water absorption of analysed flour samples increases by replacing part of wheat flour type 405 with whole grain wheat, hull-less barley or rye flour.
2. A higher dough stability was obtained for flour blends with whole wheat grain flour, comparing to blends with whole rye and hull-less barley grain flour, which could be explained with a higher gluten content of whole wheat grain flour.
3. Wheat flour (type 405) showed the lowest dough development time 2:22 min, but the higher dough development time (6:30 min) was obtained for whole wheat grain flour, whole rye grain flour (6:36 min) and for whole hull-less barley grain flour (6:52 min).
4. To obtain dough with good properties for pasta production, the 20% of wheat flour type 405 could be replaced with whole rye and hull-less barley grain flour and with 50% of whole wheat grain flour.
5. A higher gelatinization temperature was obtained for flour blends with whole wheat grain flour (90.9 °C), comparing to blends with whole rye (85.3 °C) and hull-less barley grain flour (85.7 °C).

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