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The effects of extrusion on the content and properties of dietary fibre components in various barley cultivars

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ABSTRACT

Wholemeal flour from five Czech spring barley materials was processed in a single-screw extruder at 130 °C, addition of 20% water and a screw speed of 220 rpm. Two barleys (AF Cesar, AF Lucius) were hulless cultivars with a standard starch composition, while three barleys (KM 2624, KM 2460-1, KM 2460-2) were hulled waxy lines. The effect of extrusion on content of different dietary fibre fractions was determined. Also the changes of the molar mass of β-glucan were studied. Regardless of the barley genotype (standard starch or waxy), the extrusion had no significant effect on arabinoxylan content. A significantly higher beta-glucan and soluble dietary fibre content in barley cultivars with standard starch composition was observed after extrusion. The content of insoluble dietary fibre decreased significantly in all extruded flours. The molar mass of water-extractable beta-glucan increased independently of the barley variety after extrusion. But the increase in beta-glucan extractability due to extrusion was not observed.

1. Introduction

Barley is the fourth major cereal crop in the world. From 2013 to 2014 the world production of barley was 145 million metric tonnes (www.igc.int). Most harvested barley is used for feeding, malting and brewing, and only a minor part (2–5%) is consumed by the food industry. In 2013, 1.5 million metric tonnes of barley were harvested in the Czech Republic. About 75,000 tonnes of this barley were used for food production (Ministry of Agriculture CR, 2013). Barley kernels are processed into various sizes of pearls, flakes, and white or wholemeal flour. The average daily consumption of cereal products per person in Europe is about 226 g, and the WHO/FAO recommend consuming mainly whole grain products in order to increase the daily intake of dietary fibre. Hulless barley is a good source of fibre and can be easily prepared in the whole grain form, in contrast with hulled barley varieties.

Total dietary fibre (TDF) is the most important component of the whole barley grain because it contributes to substantially lowering the risk of serious diet-related diseases as well as improving overall human health (Collins et al., 2010). The mean TDF content in hulled and hulless barley, with a standard composition of starch, is about 17% and 13%, respectively. TDF is about 20% in hulled barley and 14% in hulless genotypes of barley with a high content of amylopectin in starch (95–100%, e.g. called "waxy") (Ullrich, 2011). The major parts of TDF are non-starch polysaccharides, mainly cellulose, arabinoxylans (AX), (1 → 3) (1 → 4)-β-D-glucans (BG), and oligosaccharides. The total mixed linked BG content in barley ranges from 2 to 10% (Brennan and Cleary, 2005; Tiwari et al., 2011) and the total AX content varies from 3 to 8% (Honcu et al., 2013). The location and the content of BG in barley grain are particularly important from a technological and nutritional point of view. The nutritional value and health-promoting potential of barley depends on the composition of the kernel and is controlled by genotype, environmental growing conditions and their interactions (Ullrich, 2011). Some nutritional and health benefits of BG consumption include the maintenance of normal blood cholesterol levels as well as the reduction of rises in blood glucose levels after meals (Commision Regulation (EU) No. 432/2012). Barley grain fibre also contributes to an increase in faecal bulk. It can be expected that the

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Abbreviations

AX	arabinoxylan
BG	(1 → 3) (1 → 4)-β-D-glucans
CA	cellulose acetate
GPC	gel permeation chromatography
IDF	insoluble dietary fibre
Mw	mean molar mass
PET	polyethylene terephthalate
RVA™	Rapid Visco Analyser
SDF	soluble dietary fibre
SE	standard error
SEM	scanning electron microscopy
TCW	Thermocline for Windows™
TDF	total dietary fibre
TPEF	temperature profile of extruded flour
TPNF	temperature profile of native flour

consumption of BG may influence the risk of colon cancer and cardiovascular diseases (Collins et al., 2010; Newman and Newman, 2008). In addition to these features, the consumption of barley based products gives a feeling of satiety (Lyly et al., 2009; Wanders et al., 2011).

The extrusion process is a highly adaptable, highly productive, cost-effective and energy efficient technology with the ability to produce unique product shapes and high product quality (Sharma and Gujral, 2013; Vasanthan et al., 2002a). It is mostly carried out at high pressure, temperature and using mechanical shearing, however, low-temperature extrusion is also applied in cereal technology (Brennan et al., 2008; Gajula et al., 2008, 2009; etc.).

The chemical reactions that take place during extrusion, especially the breakdown of polymeric compounds, depend on many parameters concerning the raw materials, additives, technical equipment, and processing conditions. Rheological and physicochemical properties of the dough, and physical properties of the extruded product, are influenced by different variables such as the type of extruder, feed rate, moisture content, residence time, temperature profile in the different heating zones, screw configuration and its geometry, screw speed etc. (Sharma and Gujral, 2013).

Extrusion causes changes to the properties of the barley flour's polymeric components such as starch, protein, BG and AX (e.g. an increase of solubility and viscosity, a breakdown of polymer side chains, a partial or full starch gelatinization and/or protein denaturation and possibly formation of the inclusion complex between lipids and amylose) and it may enhance its suitability in cereal technology. Colour, flavour, and the shape and texture of the product are affected conditions that occur during extrusion. Additionally, the molar mass of the dietary fibre components (BG, AX) can be changed, however, loss of vitamins and amino acids are comparatively low, due to the short retention time of the material in the extruder.

The aim of the presented study was to investigate the changes in composition and properties of dietary fibre components in different cultivars as well as new breeding lines of barley during the extrusion process. The ways in which extrusion affected the content of BG, AX, the soluble and insoluble parts of dietary fibre, and the molar mass distribution of water-extractable BG in native and extruded barley flours were also very closely studied.

2. Materials and methods

2.1. Barley

Five types of Czech spring barley were obtained from Agrotest Fyto Ltd. (Kroměříž, Czech Republic). AF Cesar and AF Lucius were hulless barley cultivars with standard starch compositions, registered for growing in the field conditions of the Czech Republic. AF Cesar, a new cultivar registered specifically for food production, had a significantly higher BG content than AF Lucius. The other three materials (KM 2624, KM 2460-1, KM 2460-2) were the new hulled waxy barley breeding lines with higher BG and AX contents, whereas genotypes KM 2460-1 and KM 2460-2 were sister lines.

2.2. Barley processing

The hulless barley was peeled and the hulled barley was abraded before milling. Peeling and abrasion were carried out with a low-diameter hulling machine KMPL (JK Machinery Ltd., Planá nad Lužnicí, Czech Republic) in Bio-Vavřinec Ltd. (Okrouhlice, Czech Republic). The hulless barley passed through the machine once, and only at a low speed. The hulled barley passed through the machine four times at a higher speed. The weight loss of the hulless barley was 4.9% and 3.5% for AF Cesar and AF Lucius, respectively. The weight loss of the hulled barley was 14.5–15.5%. The processed materials were milled in a hammer mill (ŠK 600, Štefan Tuška Company, Slovak Republic) into native barley flours (wholemeal) with a mesh size 1 mm. Particle size distribution of the native flours was determined by a sieve analysis with 6 sieves of the mesh size: 800, 630, 500, 200, 90 and 50 μm. The flour weight used for analysis was 50 g and the analysis time was 5 min. The highest flour particle amount for cultivars with a standard starch composition was determined to be between 90 and 200 μm, namely 37%. Between sieves with the mesh size 200 and 500 μm and 50 and 90 μm identically equal amount of the flour particles was established, 27%. About 9% of the flour particles were larger than 500 μm. The highest amount of flour particles for waxy lines was measured between 50 and 90 μm, namely 45%. Between the mesh sizes 200 and 500 μm about 30% of the particles were found. About 19% of flour particles had size between 90 and 200 μm, while only 4% of the particles were bigger than 500 μm.

2.3. Extrusion

Pilot scale extrusion processes were carried out under optimal operating conditions for barley (Extrudo Bečice Ltd., Bečice, Czech Republic). The extrusion conditions were adjusted and based on verified experience. A single-screw extruder (model 60-B-9250-BL, Schaaf Technologie GmbH, Bad Camberg, Germany) with the TURBO extrusion process was used (Fig. 1). When compared to conventional screw machines, the transport, mixing, and kneading of the dough mass is realized much more efficiently. There is a tremendous pressure difference created due to the high viscosity of the dough among the front and rear sides of the arms of the rotor. Moreover, cavitation, which is generally undesirable in the extrusion process, has a homogenizing effect and ensures optimal heat transfer within the dough mass when compared to the traditional extrusion process. This way it is possible to process materials containing higher amounts of fat, sugar or fibre, and furthermore, sterilization of the materials is more effective than in other extrusion processes (e.g. single extrusion). TURBO provides better product stability, texture and flexibility, and also gives uniform shape and texture with increased capacity and dependable reproduction of the extrusion parameters of the product. Through optimized dimensioning of the turbine, pressure plates, and sequential