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Factors affecting structural properties and *in vitro* starch digestibility of extruded starchy foams containing bran

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ABSTRACT

Rye bran of two different particle sizes (coarse: 440 μm and fine: 28 μm) were prepared by milling of commercial rye bran. Coarse and fine rye bran was added into a blend of rye endosperm flour and corn starch (70:30) to achieve two bran levels, 15 or 30%, to produce directly puffed extrudates. A co-rotating twin screw extruder was used with a screw speed of 500 rpm, barrel temperature profile: 40-70-75-90-95-110-110 °C and constant feed rate of 67 g/min. Feed moisture content of 17% was used either as in barrel-water feed or as preconditioning. Fine bran addition effectively improved macrostructural properties as compared to coarse bran through increasing expansion by 3.3–11.7% and piece density by 3.8–10.5%. Reduction of bran particle size significantly ($P < 0.05$) increased crispiness by 66.7–203.3%. Particle size reduction of bran had only minor influences on cell wall thickness, cell area and hydrolysis index of the extrudates. Extrudates made with 30% fine bran at in barrel-water feed provided the crispiest extrudates with lower *in vitro* hydrolysis index. The results demonstrated that the macrostructural and mechanical properties of extrudates containing rye bran can be improved by reducing bran particle size.

1. Introduction

Rye is a key source of dietary fibre (DF) and the second most common grain after wheat used in bread production in Europe; however the use of rye in extruded snack products is limited. Snack foods are often made of refined flour and starch (corn, wheat, rice, oats and potato), and thus these products tend to be low in DF, protein and other essential nutrients (Robin et al., 2012). There is an increasing consumer demand for healthy convenience and snack foods with high DF content. Several studies have shown that consumption of DF reduces the risk of obesity, cardiovascular disease, cancer and diabetes (Smith and Tucker, 2011; Hauner et al., 2012).

Rye bran, a by-product generated during rye flour processing, consists of 38–48% DF, 14–18% protein and 13–28% starch, and therefore could be utilized as a low-cost fibre and protein source in healthy snack formulations (Alam et al., 2014). High GI (glycaemic index) foods such as starch based extruded products have been reported to associate with increasing health risks related to obesity, diabetes and coronary heart disease (Livesey et al., 2008). Thus snack products with low GI and high DF are of interest for consumers and consequently food manufacturers. Processing method, feed material composition, microstructure and textural properties of food influence starch digestibility (Singh et al., 2013). It is thus important to understand how physical, textural and microstructural properties of starchy snack foods supplemented with DF affect the digestibility of starch.

The properties of extruded products depend strongly on the raw materials, level of incorporation and the source of the DF and finally on the processing conditions (Altan and Maskan, 2011). High fibre extrusion is challenging, resulting often in highly dense, less crispy and hard textures, which are not appreciated by consumers (Robin et al., 2012; Sozer and Poutanen, 2013). Cereal fractions rich in insoluble DF have poor gas-holding capacity and interfere with the expansion of air cells (Singh et al., 2007). Addition of bran in starch based products interferes with the continuity of starchy matrix.

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Abbreviations

A_{uc}	Area under the curve
C_i	Crispiness index
C_w	Crispiness work
D	Average cell diameter
DF	Dietary fibre
GI	Glycaemic index
HI	Starch hydrolysis index
IB	In barrel-water feed
PC	Preconditioning
SDF	Soluble dietary fibre
t	Average cell wall thickness
TDF	Total dietary fibre
WAI	Water absorption index
WSI	Water solubility index
XMT	X-ray microtomography

This affects both structural and mechanical properties thus reducing the overall quality (Sozer and Poutanen, 2013).

Due to the adverse effect of cereal bran on product quality, typically only 10–32% of bran has been added in previous studies as reviewed by Robin et al. (2012) and Sozer and Poutanen (2013). Several researchers reported that more expanded, less hard and crispier extrudates could be obtained by decreasing the particle size of the feed material such as fibre and wholegrain (Lue et al., 1991; Mathew et al., 1999). To date, a number of studies have been conducted to determine the effect of insoluble fibre addition and particle size reduction on the structural and textural properties of extruded products with different fibre sources such as sugar beet fibre (Lue et al., 1991), oat-fibre and cellulose (Guan et al., 2004), wheat bran (Robin et al., 2011a; Santala et al., 2014), oat bran (Sibakov et al., 2014) and rye bran (Alam et al., 2014).

In our previous study (Alam et al., 2014) a decrease in rye bran particle size from 440 to 28 μm improved overall quality of 100% rye bran extrudates. Particle size reduction of wheat bran (702 → 84 μm) improved expansion but did not affect textural attributes when 20% wheat bran was added to rye flour based extrudates (Santala et al., 2014). Robin et al. (2011a) and Sibakov et al. (2014) observed no significant increase in degree of expansion by adding 12–24% wheat bran (317 → 224 μm) and 10% oat bran (213 → 32 μm) into wheat and defatted oat flour based extrudates, respectively. Therefore, effect of particle size reduction on structural and textural properties needs to be further evaluated through macro- (expansion), and micro-structural properties such as porosity and cell wall thickness. To the best of our knowledge literature is missing the effect of bran particle size reduction on *in vitro* starch digestibility of high fibre starchy extrudates. The aim of the current work was to understand the factors (eg. hydration regimen, dietary fibre content and particle size) effecting the structural properties and *in vitro* starch digestibility of starch-based rye bran-enriched extrudates.

2. Materials and methods

2.1. Feed material preparation

Native rye bran obtained from Fazer Mill and Mixes (Lahti, Finland) was milled to two different particle sizes, coarse and fine. Coarse (D_{50} = 440 μm) and fine (D_{50} = 28 μm) rye bran were prepared at VTT Technical Research Centre of Finland (Espoo, Finland) by milling native rye bran using a published protocol used in our previous study (Alam et al., 2014). Rye endosperm flour (with a DF content of 7%, carbohydrate of 75% and protein content of 6% as detailed in the manufacturer specifications) was obtained from Helsinki Mills Ltd., Järvenpää, Finland. Waxy corn starch with 97% of amylopectin was from Roquette Ltd., France and was used to make starch-flour mixture by adding 30% of starch into 70% of rye flour using a spiral mixer (Diosna SP 24 D, Dierks & Söhne, Osnabrück, Germany). This starch-flour mixture was used as extrusion feed together with coarse- or fine-particle sized rye bran so that the amount of bran was either 15% or 30% in the starch-flour-bran mixtures. Two different bran addition level categorises as low (15% bran: 82% starch and 8.2% DF) and high (30% bran: 74% starch and 12.6% DF) fibre feed material. Rye bran was mixed with starch-flour mixture prior to extrusion using the same spiral mixer to make the final blend of starch-flour-bran.

2.2. Particle size analyses

Particle size distribution of the milled raw materials was determined with a Laser Diffraction Particle Size Analyser (LDPSA) (Beckman Coulter LS 230, Coulter Corporation, Miami, USA) using the wet module. MilliQ-water was used as background solution. Particle size distributions were expressed in volume units and the measurements were made in duplicate.

2.3. Extrusion processing

A co-rotating twin-screw extruder (Poly Lab System, Thermo Prism PTW24, Thermo Haake, Dreieich, Germany) was used for extrusion trials using a method described by Alam et al. (2014). A full factorial experimental design was used for all extrusion trials (Table 1). The feed rate of 67 g/min, screw speed of 500 rpm and feed moisture of 17% were kept constant during the extrusion experiments. The barrel temperature profile was: 40, 70, 75, 90, 95, 110 and 110 °C in sections 1–6 and in the die. Two water addition regimens were used: in barrel–water feed (IB) and preconditioning (PC). Preconditioning was carried out by adjusting the moisture content of the bran-flour mixtures before extrusion using the protocol published by (Alam et al., 2014). The values of torque, die pressure and die temperature were monitored and recorded during the extrusion.

2.4. Macrostructural analyses

The extruded samples of each extrusion experiment were collected, dried at 105 °C for 20 min and cooled to room temperature. The measurements of expansion rate, specific length and piece density were made from 20 replicates from each extrusion treatments using the method described by Alam et al. (2014).

2.5. Microstructural analyses

In X-ray microtomography (XMT), the samples were analysed in triplicate using a method described by Alam et al. (2014). Each sample of 10 mm long pieces were scanned using a desk-top XMT system (Model 1172, SkyScan, Aartselaar, Belgium) to obtain the parameters of porosity, average cell wall thickness (t), average cell diameter (D) and average cell area. Average cell area was calculated using the formula (area = $(\pi/4) \times D^2$), where D represents average cell diameter.

2.6. Characterization of textural properties

Textural properties of extrudates were analysed by the uniaxial