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Enzymatic modification and particle size reduction of wheat bran improves the mechanical properties and structure of bran-enriched expanded extrudates

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ABSTRACT

The aim of this study was to examine enzymatic modification of wheat bran, performed in a low-moisture process, and the reduction of bran particle size as means of improving the technological performance of wheat bran in expanded extrudates. Modification of bran by hydrolytic enzymes increased the crispiness and decreased the hardness and piece density of extrudates containing wheat bran and endosperm rye flour in 20:80 ratio. These improvements correlated ($P < 0.01$ or 0.05) with an increased content of water extractable arabinoxylan and decreased water holding capacity of the bran, as well as with increased longitudinal expansion of the extrudates. Furthermore, bran with a fine average particle size (84 μm) produced extrudates with improved mechanical properties and higher radial expansion than coarse bran (particle size 702 μm). The impact of bran particle size was also observed in the cellular structure of the extrudates as differences in cell size and homogeneity. The bran drying method, oven or freeze drying after enzymatic modification, did not have a major impact on the properties of the extrudates. The study showed that the functionality of wheat bran in extrusion can be improved by enzymatic modification using a low-water process and by reduction of bran particle size.

1. Introduction

Extrusion technology is a versatile option for the production of different types of ready-to-eat snacks with puffed structure and cooked characteristics appealing to consumers (Brennan et al., 2013). During the past 10–15 years, consumers have become more health conscious and are increasingly demanding tasty snack products which satisfy their hunger and yet are low in fat, rich in dietary fibre (DF) and preferably fortified with vitamins and minerals (Brennan et al., 2013). Wheat bran is a good source of DF and contains a relatively high amount of protein and phytochemicals. However, as recently reviewed by Robin et al. (2012) and Sozer and Poutanen (2013), increasing the amount of DF or bran in extrusion formulations typically causes deterioration of the textural properties of the product, e.g. by increasing the density and hardness and decreasing the expansion volume and crispiness of the product. Extrudate expansion, which is crucial for the formation of the appetizing and crispy textures, is governed by a complex series of events, in which starch plays a major role (Moraru and Kokini, 2003). The impact of DF on the texture of extruded products is generally considered to depend mainly on its interactions with starch and on its effects on the mechanistic steps of expansion, i.e. starch transformation, nucleation of bubbles, extrudate swell, growth of bubbles, and bubble collapse (Moraru and Kokini, 2003; Robin et al., 2012). Particularly insoluble DF (IDF) has been reported to be detrimental to the extrudate characteristics (Robin et al., 2012). The adverse effects of IDF in extrusion have been related to the changes they cause in the rheological properties of the batter melt and in the amount of free water available for starch transformations and expansion, as well as to the physical disruption of the continuous starch matrix and gas cell walls by the fibre particles (Pai et al., 2009; Moraru and Kokini, 2003; Robin et al., 2012).

Different strategies have been studied as a means to improve the technological performance of DF ingredients in extruded products. Decreasing DF ingredient particle size has been reported to increase the expansion of extrudates containing DF (Lue et al., 1991; Blake, 2006; Alam et al., in press). However, particle size

Abbreviations: AX, arabinoxylan; C_i, crispiness index; DF, dietary fibre; DM, dry matter; ER, expansion rate; F_{cr}, crushing force; F_{max}, maximum point of the force-deformation curve; IDF, insoluble dietary fibre; SDF, soluble dietary fibre; WEAX, water extractable arabinoxylan; WHC, water holding capacity.

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reduction has not improved expansion when the size differences or addition levels are low (Robin et al., 2011; Blake, 2006; Alam et al., in press). It has also been reported that soluble DF (SDF), such as pectin, inulin or guar gum, generally performs better than fibres that are mostly insoluble (IDF), e.g. wheat bran (Yanniotis et al., 2007; Brennan et al., 2008), and it has been suggested that increasing the solubility of DF prior to extrusion could be a means to improve the functionality of DF in extruded products (Robin et al., 2012). However, only a few studies have examined this possibility. Pai et al. (2009) showed that increasing the SDF content of corn bran with concomitant reduction of IDF by a chemical treatment resulted in higher expansion as compared to untreated bran. The improved expansion was related to favourable changes in melt viscosity and better interaction of SDF with starch (Pai et al., 2009).

Modification of bran by enzymatic processing has been shown to facilitate the addition of bran, and thus DF, to food products, and the beneficial effects of these processes have often been related to the transformation of IDF to SDF (Lebesi and Tzia, 2012; Coda et al., 2014). However, to our best knowledge, enzymatically modified bran has not previously been studied as an ingredient in extrudates. Enzymatic treatments are typically preformed in high water content, which is not economical, especially if the modified ingredient should be dried prior to its subsequent use in a low moisture process such as extrusion. On the other hand, enzymatic processing at low water content, i.e. high consistency, typically causes reduction of enzyme action and requires a substantial amount of energy for mixing. It has been shown that efficient xylanase action on wheat bran at low water content and without continuous mixing can be accomplished by the use of an extruder-aided pre-mixing process (Santala et al., 2013a).

In the current study the enzymatic degradation of wheat bran was investigated as a means of improving the quality of bran-supplemented endosperm flour-based expanded extrudates. The aims were 1) to study the impact of different variations of the extruder-aided low-moisture enzymatic treatment and the subsequent drying step on the physicochemical properties of wheat bran of two different particle sizes, and thereafter 2) to study how the physicochemical properties of the modified bran ingredient and the reduction of bran particle size affect the macro- and microstructure and mechanical properties of bran-supplemented expanded extrudates.

2. Materials and methods

2.1. Cereal raw materials

Commercial wheat bran (Fazer Mill & Mixes, Lahti, Finland) was ground by TurboRotor technology (Mahltechnik Görgens GmbH, Dormagen, Germany) to two different levels of fineness so that the mean particle sizes were 702 μm (hereafter referred as coarse bran) and 84 μm (fine bran). The grinding process did not contain any sieving or fractionation steps, thus the fine and coarse bran were composed of the same bran raw material. The high air throughput and short residence times used in the grinding technology ensured that the product temperature remained below 45 °C, thus avoiding the heat damage often associated with intensive grinding treatments. The total and water soluble DF contents were 49.9 and 6.7% in the coarse and 48.0 and 8.2% in the fine bran, respectively. Arabinoxylan content was 20.5% (coarse) and 20.6% (fine) and starch content was 16.7 (coarse) and 16.5% (fine).

Rye endosperm flour (Helsinki mills ltd. Järvenpää, Finland) was used as a base material for the expanded extrudates. The total and soluble DF contents were 11.8% and 9.6%, respectively, and the starch content was 84.7%.

2.2. Enzyme preparations

Commercial hydrolytic enzymes, Depol 761P (Biocatalysts Ltd, Cardiff, UK), a xylanase preparation derived from *Bacillus subtilis,* and Veron CP (AB Enzymes GmbH, Darmstadt, Germany), a cellulolytic enzyme preparation with hemicellulase side activities from *Trichoderma reesei*, were used either individually or in combination for the bran treatments. The activity profile of Depol 761P, endoxylanase 28,660 nkat/g, polygalacturonase 1,317 nkat/g, β-glucanase 1,625 nkat/g, α-amylase 44 nkat/g, and β-xylosidase 2 nkat/g, was previously reported by Santala et al. (2013b). The activity profile of Veron CP, determined by the methods described by Santala et al. (2013b), was as follows: endoglucanase 18974 nkat/g, cellulase (filter paper as substrate) 53 filter paper units/g, β-glucanase 75760 nkat/g, xylanase 14610 nkat/g, β-xylosidase 257 nkat/g, polygalacturonase 8469 nkat/g, mannanase 3022 nkat/g, α-arabinosidase 530 nkat/g, β-glucosidase 528 nkat/g and α-amylase 94 nkat/g. The preparation was free from ferulic acid esterase and proteinase. Enzyme preparations were dosed according to their xylanase activity at 200 nkat/g bran dry matter (DM) (treatments with Depol 761P) or 100 nkat/g (treatments with Veron CP, corresponding to an endoglucanase activity of 130 nkat/g). For the treatments with a combination of the enzymes, the dosages as xylanase activity were 200 nkat Depol 761P and 100 nkat Veron CP/g bran DM.

2.3. Production of enzymatically modified bran

Bran modification was performed by extrusion-aided enzyme treatment as described by Santala et al. (2013a). 450 g of bran with an initial moisture content of 10.7% (coarse) or 5.5% (fine) was first mixed with the enzyme preparation(s) (in powder form) and preconditioned to a moisture content of 20% by adding water slowly while mixing (speed setting 2) with a Kenwood KM300 mixer (Kenwood Ltd., Havant, UK) with a K-shaped blade for 2 min. Preconditioning was also performed for the blank treatments (i.e. without enzyme addition). The pre-conditioned bran mixture was transferred to the feeding unit (a co-rotating twin screw feeder, K-Tron Soder, Niederlenz, Switzerland) of a twin screw extruder (APV MPF 19/25, Baker Perkins Group Ltd, Peterborough, UK) within 20 min and fed to the extruder at a rate of 26 g/min. The screw configuration is presented in Fig. 1. The barrel temperature was 50 °C and the screw speed was 65 rpm. Water was pumped to the beginning of the barrel at an appropriate rate in order to obtain moisture contents of 48 ± 1% in the bran mixture. Bran mixture was collected continuously from the die exit (diameter 3 mm) and the collected material was transferred every 2 min either to incubation (at 50 °C for 4 h in sealed containers) or to drying, which was performed either in an oven (samples spread on metal trays and dried with air circulation at 50 °C for 18–20 h) or by freezing the sample in liquid nitrogen for subsequent freeze drying. The incubated samples were also immediately dried by oven drying or by freeze drying. The dried samples were ground in a mill (Hosokawa Alpine, 100 UPZ, Retsch GmbH, Germany) with two different settings (coarse bran samples with sieve size 0.5 mm and rotor speed 6000 rpm; fine bran samples with a 0.3 mm sieve and 18 000 rpm) in order to maintain the different particle sizes of the two bran types (coarse and fine).

2.4. Production of expanded extrudates

Bran samples were mixed with rye endosperm flour in a 20:80 ratio on a dry matter basis in a Kenwood KM300 mixer (Kenwood Ltd., Havant, UK) with a K-shaped blade for 4 min. The same extruder, feeder and die were used as for the bran treatments. The