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Effect of size reduction by freeze-milling on processing properties of beta-glucan oat bran

Joanna Harasym [a, *], Dominika Suchecka [b], Joanna Gromadzka-Ostrowska [b]

[a] Food Biotechnology Department, Faculty of Engineering and Economics, Wroclaw University of Economics, ul. Komandorska 118/120, 53-345 Wroclaw, Poland

[b] Department of Dietetic, Faculty of Human Nutrition and Consumer Sciences, Warsaw University of Life Sciences, ul. Nowoursynowska 166, 02-787 Warsaw, Poland

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ABSTRACT

An effect of freeze-milling on processing properties of beta-glucan oat bran has been evaluated. A comparison with existing, patented methods of high molecular weight oat beta-glucan has been carried out. The new method employs raw material pre-treatment with freezing and milling in a hammer mill, resulting in significant reduction of particle size – 89% was between 80 and 50 μm in comparison with initial material when 79% were between 250 and 200 μm. Reduction of particle size also improved some process parameters of extraction technology – 30% improvement in fat removal during first stage of beta-glucan recovery was observed. The achieved pilot plant yield of product containing beta-glucan extraction was 64,03%, purity (ie. beta-glucan content), of achieved product was 84,4% and average molecular weight was about 69,500 g/mol.

1. Introduction

Many studies have shown that (1 → 3) (1 → 4)-β-D-glucan from oat is not only effective in LDL cholesterol level reduction (Tiwari and Cummings, 2011) but in post-prandial glucose level lowering and insulin response suppression as well (Panahi et al., 2007). The scope and evaluation of those studies were sufficient enough to enable the European Food Safety Authority to release two health claims for oat beta-glucan – for cholesterol level reduction and for lowering of post-prandial glycemic response. Physiological activity of oat beta-glucan has often been attributed to its ability for increasing viscosity in the upper digestive tract (Dikeman and Fahey, 2006).

An immunomodulatory effect of (1 → 3) (1 → 4)-β-D-glucan from oat and barley has also been recognized (Noss et al., 2013) and was connected, not only with 1–3 linkage but with specific branching 1–4 and 1–6 as well. Those effects are more deeply recognized for fungal beta-glucans and an indication was made on the degree of branching, polymer length and tertiary structure, but it is still difficult to confidently make generalizations because of the often contradictory data available (Estrada et al., 1997).

Most of the oat beta-glucan preparation methods gave attention to preserving the high molecular weight of polymer chains, connecting health benefits with molecular weight related viscosity (Sibakov et al., 2012). Some attempts have been made to improve functional application of oat beta-glucan by depolymerization as its high molecular weight related viscosity creates some restrictions in food application (Sibakov et al., 2013). It has been reported that the depolymerization method by high pressure homogenization (Laakso and Lehtinen, 2005), sonication (Vårum et al., 1992), adding ascorbic acid (Kivelä et al., 2009), enzymatic hydrolysis (Shimokawa et al., 1996), thermo-mechanical degradation in extrusion (Tosh et al., 2010), acid- or enzyme-catalyzed depolymerization at reduced water content (Kaukovirta-Norja et al., 2009) or gamma-irradiation (Sung et al., 2009) have been used to improve the physical and functional properties of beta-glucan. Although these methods are effective in decreasing the molecular weight, they do have certain disadvantages such as a high cost, low yield, long processing time and temperatures (Sibakov et al., 2013) which restrict their application on a plant scale.

Abbreviations: LDL, Low-density lipoprotein; MW, molecular weight; EtOH, 96% ethyl alcohol food grade; ZM1, ZM 2, ZM 3, ZM 4, ZM 5, reaction tank 1, 2, 3, 4, 5; SS1, SS2, vibrating sieve 1,2; HCl, hydrochloric acid; NaOH, sodium hydroxide; WO1, centrifuge; ST1, tray dryer; BG, beta-glucan preparation; BGC, control beta-glucan preparation.

* Corresponding author. Tel.: +48 713680249; fax: +48 713680771.
E-mail address: joanna.harasym@ue.wroc.pl (J. Harasym).

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There is a lack of widely designed human diet intervention studies, comparing the health benefits (lipid metabolism, sugar metabolism, protein metabolism, immunomodulatory effects etc.) of oat beta-glucan in relation to its molecular weight. Immerstrand et al. (2010) in their study, evaluated cholesterol-lowering effects of various oat bran preparations differing in molecular weight (MW) of − glucans (2348, 1311, 241, 56, 21 or <10 kDa in C57BL/6NCrl mice.) The results suggest that the molecular weights and viscous properties of beta-glucan in oat products may not be crucial parameters for their cholesterol-lowering effects. The evaluation was made for bran products, not for isolated beta-glucan preparations and some interaction connected with insoluble fiber presence and bioactive components of plant cell walls are neglected. But the conclusion which was made can also be important for isolated beta-glucan products, as it allows the hypothesis that properties connected with viscosity ie. cholesterol level lowering effects might be maintained with immuno-properties enhanced also for low molecular weight beta-glucan. Mechanical treatment of polysaccharide raw material has been validated as a good method for reduction of particle size and several milling devices were studied for further processing facilitation (Niemi et al., 2012; Benito-Román et al., 2010). Some more opportunities appeared with freeze-milling unit development and freeze-milling has been recognized as very efficient for cellulose homogenization (Laumer et al., 2009). Wet-milling is a most often used technology in the food industry, resulting in very fine particle size, but for beta-glucan recovery is not so applicable due to its gelling properties in water. Some attempts has been made in replacing wet-milling in cereal processing with freeze-milling, Ngamnikom and Songsermpong (2011) tested three different types of grinders (hammer mill, roller mill, and pin mill) both the freeze and the dry grinding processes for rice flour. Achieved results show that, freeze grinding with the hammer mill, significantly reduced both the average particle size and the damaged starch content and produce a higher yield after sieving in comparison with dry grinding using an identical grinder. The comparison with wet the grinding process demonstrated significantly higher specific energy consumption (13,868 kJ/kg) due to the large consumption of electrical energy by many machines in the process, while the energy consumption of freeze grinding was similar to dry grinding.

Hence, the aim of the present study is to evaluate the effect of freeze-milling in a cross beater mill applied as a pre-treatment of raw material in the extraction of oat bran for beta-glucan recovery in pilot plant scale.

2. Materials and methods

2.1. Raw material and reagents

Commercially available oat fiber with 20% (declared) content of 1-3,1-4-beta-D-glucan (MICROSTRUCTURE) was used for the oat beta-glucan extraction process. Basic chemical content declared by the manufacturer and recalculated for dry matter is presented in Table 1. All chemicals used in the extraction procedure were food grade.

2.2. Description of process flow

Control oat beta-glucan preparation was carried out according to the Harasym et al. (2011) procedure demonstrated on Fig. 1. Oat fiber (15 kg) was suspended in water/EtOH 40–60% solution in the ratio 1:6 (w/w) and heated for 1 h in 70–80 °C with frame mixing as pre-treatment in a stirred batch tank reactor with heating mantle (ZM1 − 300 l, Obram Ltd). After cooling to 20–25 °C, fiber particles were separated on a vibrating sieve unit (SS1, A40S-1-66, AMKCO) with 125 μm mesh size. Cooled rinsed fiber was manually transported to a stirred batch tank reactor with heating mantle (ZM2 − 2000 l, Obram Ltd.) and then extracted in water (1:40 w/w) alkalized with NaOH, 0.1 M to pH = 8–10 at a temperature of 80 °C for 2 h. After cooling down to 20–25 °C, fiber particles were separated on a vibrating sieve unit (SS2, A40S-1-66, AMKCO) with 200 μm mesh size. The separated solution was acidified with concentrated HCl (35–38%) to pH = 4–5 in a stirred batch tank reactor (ZM4 − 2000 l, Obram Ltd.) and protein precipitation occurred. The solution with precipitated proteins was subsequently centrifuged at 11,000 *g* on a disc centrifuge with 1000 l/h flow speed (WO1, CSC 15-6-477, GEA Westfalia) for protein separation. The supernatant was delivered into a stirred batch tank reactor with heating mantle (ZM2 − 2000 l, Obram Ltd) and was neutralized by addition of NaOH solution (0,1 M) till pH = 7.0. After neutralization, EtOH (96% v/v) was added until a final concentration of 50–55% (w/w). Oat beta-glucan precipitated from the solution was separated on a vibrating sieve unit (SS1, A40S-1-66, AMKCO) with 125 μm mesh size and dried in a tray dryer (ST1,V-200, EKOTECH).

Oat fiber for low molecular weight beta-glucan extraction was prepared by freezing oat bran for 24 h at −20 °C in a freezer (M 410, New Brunswick Scientific), then milling frozen material in a cross beater mill (SK 100, Retsch) with 200 μm mesh size, collected and freezed again. Freeze-milling in a hammer mill was evaluated as the most efficient for particle size reduction (Barbosa-Canovas et al., 2005). Grinding takes place in the cross beater mill using a hammering, impact and shearing action. The feed material passes through the hopper directly into the centre of the grinding chamber. It is then caught by the cross beater and crushed between the impact plates of the cross beater and the toothed grinding insert.

2.3. Pilot plant extraction line

A pilot plant extraction line is located in Wroclaw Technology Park and was established under Polish national development programme – Operational Programme – Innovative Economy 2007–2013. It was designed by Harasym et al., in 2009 as a training pilot plant for scientists and SMEs included in NUTRIBIOMED Cluster. Fig. 2 shows the schematic layout of the selected process unit connection necessary for beta-glucan preparation according to Harasym et al. (2011).

For control beta-glucan preparation, the process route was:

ZM1⇨ SS1⇨ ZM2 ⇨ SS2 ⇨ ZM4⇨WO1⇨ZM2⇨ SS1⇨ ST1

For the low molecular beta-glucan preparation, the process route was:

ZM1⇨WO1⇨ZM2⇨WO1⇨ZM4⇨WO1⇨ZM2⇨ SS1⇨ ST1

The changes in route were made due to different processing requirements resulting from raw material milling pre-treatment,

Table 1
Raw material chemical content.

	Protein [g/100 g]	Carbohydrate [g/100 g]	Fat [g/100 g]	Beta-glucan content [%]	Total dietary fiber [g/100 g]	
					Soluble	Insoluble
Declared	16.0	23.14	7.14	20.0	44.0	
					22.86	21.14
Calculated on dry matter	17.7	25.63	7.91	22.1	48.73	
					25.31	23.42