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The effect of extrusion on the functional properties of oat fibre

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ABSTRACT

Extrusion is an effective method for the production of healthier snack foods, such as oat fibre products. The effect of this process on the physicochemical properties of oat fibre preparations containing high levels of β-glucan, however, has not been fully addressed. Oat fibre containing 28 g/100 g β-glucan was extruded using two levels of feed moisture (50 g/100 g or 60 g/100 g of feed materials) and two screw speeds (200 rpm or 300 rpm) at a constant barrel temperature profile (80 °C, 90 °C, 100 °C, 110 °C). A higher specific mechanical energy applied during extrusion correlated with an increase in specific surface area, greater sorption of water vapour and higher sorption energy for the monolayer of water associated with the surface of extruded products. The pasting properties of oat fibre were largely retained and the extent of molecular fragmentation was small, as the molecular weight of the soluble fraction, total soluble solids and water absorption index were not significantly altered. These data demonstrate that extrusion under these conditions can be applied to oat fibre preparations with high β-glucan content, resulting in oat products that retain their functional properties and potential health benefits.

1. Introduction

Extrusion processing is a popular, low cost technique that can efficiently produce a broad range of versatile food shapes from oat fibre or similar ingredients but this process can chemically and physically alter the feed (Brennan, Derbyshire, Tiwari, & Brennan, 2013). The high temperatures, high pressures and mechanical forces applied during extrusion can break covalent bonds and disrupt physical structures of macromolecules leading to a change in their functional properties (Kim, Tanhehco, & Ng, 2006; Singh, Gamlath, & Wakeling, 2007). Extrusion variables such as the screw speed, screw configuration, barrel temperature and feed moisture can affect the functional properties of food ingredients, including viscosity, solubility, thermal and pasting properties (Ali, Hanna, & Chinnaswamy, 1996; Cindio, Gabriele, Pollini, Peressini, & Sensidoni, 2002; Miller & Mulvaney, 2000).

While extrusion processing is known to affect the functional characteristics of oat flour (Gutkoski & Eldash, 1999) and oat bran (Zhang, Liang, Pei, Gao, & Zhang, 2009), the effect of oat fibre components, such as dietary fibre, proteins and lipids, on the changes experienced during processing is not fully understood. The effect of process variables, such as feed moisture content and screw speed on the functional properties of oat fibre preparations has also not been fully established. Conditions of low moisture (15–18 g/100 g of feed materials) and high temperature (150–180 °C) are known to reduce the viscosity of oat fibre β-glucan by 27% (Sharma & Gujral, 2013). High temperatures and high screw speeds (180 °C and 600 rpm) also decreased the solubility and swelling properties of oat soluble dietary fibre from 69% to 47% and 1.08 to 1.03, respectively (Zhang et al., 2009). Such physical and structural changes can also potentially influence the functional characteristics and nutritional properties of oat ingredients (Lazaridoua et al., 2004).

Oat fibre preparations with enhanced levels of β-glucan are of particular interest, as they can increase dietary soluble fibre and make it easier to deliver the recommended 3 g β-glucan per day, which has been shown to reduce blood cholesterol and normalize blood sugar levels (Lazaridou & Biliaderis, 2007; Mahdavi, Jafari,

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Ghorbani, & Assadpoor, 2014). Previous studies have typically examined oat fibre with low levels of β-glucan (3.44–4.76 g/100 g in oat flour (Choi et al., 2012), 5 g/100 g in commercial oat fibre (Rosell, Santos, & Collar, 2009) and 14 g/100 g in oat bran (Tosh et al., 2010)). While the potential of high levels of oat soluble dietary fibre (OSDF) has been demonstrated with an extracted preparation containing 82.5 g/100 g OSDF (Zhang et al., 2009), this preparation lacked other oat fibre components, such as oat protein that are known to contribute functionality to oat ingredients (Kim & White, 2012).

This study aims to investigate the effects of extrusion processing on whole oat fibre preparations containing 28 g/100 gβ-glucan. The effect of two barrel moisture contents (50 g/100 g – 60 g/100 g) and two screw speeds (200–300 rpm) were examined. The molecular weight, total soluble solids and water sorption index and dynamic vapour sorption characteristics were analysed. This later method has been applied to a wide range of dried foods but not to oat fibre; it provides a sensitive method to assess interactions with water that are governed by food structure and can potentially provide novel insights into the extrusion process. Thermal and pasting properties of oat fibre were also measured after extrusion.

2. Materials and methods

2.1. Materials

Oat fibre (Oatwell 28 g/100 g β-glucan) was purchased from Brenntag Pty Ltd (Victoria, Australia). The oat fibre composition is shown in Table 1. The protein content was analysed using a LECO FP-2000 Nitrogen Analyser (LECO Australia Pty Ltd., New South Wales, Australia). The measured nitrogen content was converted to total protein content by applying a conversion factor of 5.83. The quantification of β-glucan, lipid and total solids was carried out based on the AOAC Official Method 995.16 (AOAC., 2005), Australian Standard Method (Standards Association of Australia, 1988) and AOAC official method 990.20 (AOAC., 1993), respectively. All gel permeation chromatography solvents were purchased from Merck (Victoria, Australia).

2.2. Extrusion processing

The oat fibre was extruded by a co-rotating twin-screw extruder (MPF 19:25, APV Barker Ltd., Peterborough, United Kingdom). The barrel diameter was 19 mm and the length to diameter ratio (L/D) was 25. The dry feed (100% oat fibre) was fed with a twin-screw volumetric feeder (K-MV-KT20; K-Tron LLC, Niederlenz, Switzerland). The die pressure was monitored with a pressure transducer (Terwin 2076, Terwin Instrument Ltd., Nottinghamshire, United Kingdom) fitted into the die block. The temperature in the barrel was increased from 80 °C in the first zone of the barrel to 90 °C and 100 °C in successive zones before reaching 110 °C in the final zone at the die. Deionised water was injected into the extruder to achieve two levels of total moisture content in the barrel. The moisture contents of sample within the barrel were 50 g/100 g and 60 g/100 g on a dry basis for the low and high moisture treatments, respectively. . These levels of moisture content were higher than settings typically used for extrusion because of the strong water absorption capacity of oat fibre (Skendi, Biliaderis, Lazaridou, & Izydorczyk, 2003). The screw speed is a further process variable that was also adjusted to 200 rpm (low speed) or 300 rpm (high speed). These screw speeds are commonly used in small-scale extruders (Ding, Ainsworth, Plunkett, Tucker, & Marson, 2006; Zhang, Bai, & Zhang, 2011). Extruded oat fibre samples were made in duplicate for each treatment. The extrusion process variables and measured parameters are presented in Table 2.

The rate of dry feed and water addition were adjusted so that the rate at which the material entered the extruder (total dry feed plus water) was 4 kg/h. After extrusion, samples were dried at 50 °C for 4 h in a hot air oven (Contherm, Thermotec 2000; Wellington, New Zealand). Samples were sealed in high vapour barrier plastic bags and kept at 4 °C prior to analysis.

Table 1
Oat fibre composition.

Components	Content (g/100 g)
protein	27.11 ± 0.02
β-glucan	27.54 ± 1.12
lipids	5.23 ± 0.02
moisture	6.60 ± 0.20
carbohydrates and dietary fibre	33.51 ± 0.50

2.3. Specific mechanical energy (SME)

For each treatment, the specific mechanical energy (SME) input was calculated using the following equation (1) (Ryu & Ng, 2001):

$$\mathrm{SME} = \frac{\text{rpm (test)}}{\text{rpm (rated)}} \times \frac{\%\ \text{Motor load}}{100} \times \frac{\text{Motor power (rated)}}{\text{Feed rate}} \quad (1)$$

The unit for SME is Wh/kg. The set screw speed during extrusion is the “rpm (test)” and the “rpm (rated)” is the rated screw speed of the drive motor for the extruder (500 rpm). The rated motor power was 2.0 kW and the feed rate is the total mass input of dry-feed and water injection rate (kg/h). The % motor load (or % torque) is an output parameter displayed on the control panel of the extruder while running the extrusion.

2.4. Moisture content

The moisture content (MC) of the dry feed and the extrudates (either before or after drying) were measured with a moisture analyser (HB43-S, Mettler Toledo, Victoria, Australia). The extrudates were ground using a grinder (CG2B, Breville, New South Wales, Australia) and screened through a 250 μm sieve before analysis.

2.5. Molecular weight

The molecular weight of the soluble fractions of oat fibre was determined before and after extrusion. Samples were suspended in water (1 g/100 g). The aqueous phase of the dispersion was collected after centrifugation at 12,000×*g* for 10 min. The supernatants were then filtered through a 0.45 μm filter (Millex-HP, Merck Millipore, Cork, Ireland) and used for molecular weight measurements. A Shimadzu liquid chromatography system fitted with a Shimadzu RID-10 refractometer (λ = 633 nm), using three waters ultrahydrogel columns in series ((i) 250 Å porosity, (ii) 6 μm diameter bead size; and (iii) 10 μm diameter bead size)) was operated at room temperature. The eluent was Milli-Q water containing 20 mL/100 mL Acetonitrile and 0.1 mL/100 mL Trifluoroacetic acid (TFA) at a flow rate of 0.5 mL min^{-1}. Astra software (Wyatt Technology Corp., Version 5.3.4.14) was used to process the data to determine the molecular weights of samples. Polydispersity (Pd), a measure of the distribution of individual molecular masses, was calculated as a ratio between the average of molecular weight (Mw) and the number average molecular weight (Mn). These numbers were calculated based on the peaks obtained from