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Effects of diverse food processing conditions on the structure and solubility of wheat, barley and rye endosperm dietary fibre

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ABSTRACT

The effects of archetypal food processing conditions (dough formation, baking, extrusion, and cooking/boiling) on dietary fibre structure and extractability from the endosperm flours of rye, hull less barley and wheat are reported. For all flours and processes, the distributions of soluble/insoluble cell wall dietary fibre as well as the chemical composition (arabinoxylan (AX) branching patterns, β-glucan DP3/DP4 (DP = degree of polymerisation) ratios) of solubilised fractions were characterised. The results show that overall the total amounts of AX and β-glucan (BG) were not significantly affected by processing but that there were similar increases in the soluble fibre fraction (20–29%) for baked, extruded, and boiled/cooked processes for each flour, with lower (10–15%) increases for all flours processed into dough. In all cases, solubilised fractions of AX and BG had very similar chemical structures to the starting flour, suggesting that increased solubilisation was not due to specific chemical fractions. Confocal images illustrate loosely-held associations of β-glucan with the cell walls of processed foods in contrast to some of the arabinoxylans which appear more tightly held within the residual cell walls. The similarities in behaviour across the three grains are consistent with mechanical treatments during food preparation resulting in similar extents of disentanglement of physically-constrained AX and BG leading to their partial solubilisation.

1. Introduction

Non-starch polysaccharides (NSP) are found in cereal endosperm cell walls, as well as the aleurone layer, the bran and the husk (Nino-Medina et al., 2010) and form a major portion of dietary fibre in many diets. The nutritional benefits of dietary fibre include positive effects on important biomarkers including increased microbial fermentation, promotion of beneficial microflora, lowered plasma cholesterol (Lewis and Heaton, 1999; Moore et al., 1998; Ou and Kwok, 2004; Srinivasan et al., 2007), and controlled glycemia (Bird and Topping, 2008; Jenkins et al., 1986; Muralikrishna et al., 2007; Plaami, 1997; Shelat et al., 2010). Other benefits include reduction in colo-rectal cancer (Shewry, 2009; Vitaglione et al., 2008), and increased faecal bulk and therefore relief from constipation (Lazaridou and Biliaderis, 2007).

The two main components of all common cereal endosperm flour cell walls are arabinoxylan (AX) and (1,3;1,4)-β-glucan (BG), whose chemical structures are based on a β-(1,4)-linked xylan backbone decorated with α-(1,2) and/or α-(1,3)-linked arabinose (AX) or unbranched chains of a block co-polymer of mostly cellotriose (DP3) and cellotetraose (DP4) connected by β-(1,3) linkages (BG).

As cereals are primarily consumed in the form of processed food, it is important to ascertain the effects of processing on dietary fibre levels, solubility, and functionality within cereal endosperm flours. Major generic processing conditions include dough formation and bread baking, noodle manufacture, and extrusion. Extrusion is widely used in the cereal food processing industries, involves the application of high heat, high pressure, and shear forces to an uncooked mass (Zhang et al., 2011), and is commonly used to produce breakfast cereals and snack foods.

The aims of this study were therefore to characterise the effect of archetypal food processing operations on dietary fibre extractability, structure and properties for each of three cereal endosperm flours (wheat, rye, hull-less barley) in order to systematically study the effect of raw materials and food processes on potential health-benefiting properties.

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2. Materials and methods

In this study, a series of cereal food processing conditions were applied to each of wheat, hull-less barley and rye. These processing conditions were selected to be typical of the wide range of treatments experienced in cereal-based foods, although some were unusual for one or more of the cereal starting materials. The treatments assessed were dough formation and baking (relevant to bread formation), extrusion (relevant to breakfast cereal and snack product production) and yellow alkaline noodle (YAN) manufacture. YAN was used as an example of not only boiling and cooking in water, but also of chemical (alkali) process treatment effects. The introduction of the alkali serves to toughen the noodle and impart the characteristic yellow colour, aroma and firm texture (Hatcher et al., 2005).

2.1. General characterisation

2.1.1. Materials

Wheat endosperm flour (2010 Australian: unknown variety) was purchased from the Macro Food Company, Queensland. Rye endosperm flour (2010: *Bevy*) was purchased from Laucke Mills, South Australia; Barley hull-less endosperm flour (2010: *Finnis*) was obtained from the University of Adelaide, Waite Campus; South Australia. All flours were milled using commercial break rollers, were devoid of bran and husks (i.e. contained predominantly endosperm), and had particle sizes <150 μm. Before use, flours were sifted through a 75 μm mesh and particles that came through the sieve were discarded. Full analytical characterisation of these materials, and all other materials used for analytical methods have been detailed in (Comino et al., 2013, 2014).

2.1.2. Methods

Endosperm flours from rye, wheat, and hull-less barley were processed and fractionated into soluble (water extractable) and insoluble cell walls after removal of starch and protein using the methods detailed in (Comino et al., 2013). Extractions were performed in duplicate unless otherwise stated. The processed water extractable fractions were characterised using HPLC (high performance liquid chromatography) for monosaccharide contents. The processed insoluble cell wall fractions were characterised by monosaccharide analysis, β-glucan analysis and DP3/DP4 ratios, and confocal microscopy. The unfractionated processed foods were also analysed for monosaccharide contents, β-glucan content and DP3/DP4 ratios, and microstructure (confocal microscopy).

The monosaccharide analysis, and total β-glucan assays were performed as per (Comino et al., 2013). Histological sample preparation, immuno-labelling of AX and BG, and confocal imaging microscopy were performed as described (Comino et al., 2014).

2.1.2.1. Analysis of DP3/DP4 ratios. The β-glucan DP3/DP4 ratios were determined after lichenase digestion as per the mixed-linkage β-glucan assay kit (AOAC Method 995.16) (Association of Official Methods of Analysis, 2006) from Megazyme (Wicklow, Ireland), using high performance anion exchange chromatography (Dionex ICS-5000; Column: Dionex CarboPac PA200 3 × 250 mm + guard), at a temperature of 35 °C. The injection volume was 25 μL and the eluents used were A) 0.1 M sodium hydroxide and B) 0.1 M sodium hydroxide, 1 M sodium acetate. Flow rate: 0.5 mL/min with a gradient as follows.

Gradient:	Time (min)	0	9	10	11	12	20
	%B	1	9	100	100	1	1

All gradient segments were linear, and detection used a pulsed amperometric detection (PAD), 20 °C, Gold Standard PAD waveform. The area under the peak was quantified by comparison to a BG-OS (β-glucan oligosaccharides) DP3 and DP4 standard curve.

2.1.2.2. Statistical analyses. Statistical analyses were performed using Minitab software version 16 (Minitab Inc., State College, PA, USA) to calculate means ± SD (standard deviation) of values measured for each sample. All significant differences are reported at a significance level of 0.05.

2.1.3. General food processing materials

Dough and bread ingredients and recipes (dry basis % w/w): 96% w/w flour (either wheat, hull-less barley or rye), 2% w/w yeast (Tandaco Dry Yeast from Cerebos Foods; Seven Hills, NSW, Australia), 1% w/w sugar (CSR, Yarraville, Victoria, Australia), and 1% w/w NaCl (Sigma–Aldrich, St Louis, MO, USA). Water was added at 36% w/w (of the total dry w/w% formulation). An additional 20% w/w of water (or 56% w/w of the total dry w/w% formulation) was added to the hull-less barley flour to enable a dough to be formed due to the different hydration absorption properties of the flour.

Extruded product ingredients and recipes (dry basis %w/w): 98.7% w/w flour, 0.78% w/w NaCl, 0.48% w/w emulsifier (Dimodan® Danisco Australia Pty Ltd; Botany, New South Wales (NSW), Australia) and 0.04% w/w α-tocopherol (Danisco Australia Pty Ltd; Botany, NSW, Australia) (King et al., 2008). Water was added at 20–25% w/w (of the total dry w/w% formulation) for the wheat and rye flours, whilst for the hull-less barley, water was added at 48% w/w (of the total dry w/w% formulation). The screw speed was 200 rpm and the configuration used is detailed in Fig. 1.

Alkaline yellow noodle ingredient and recipe was adapted from Morris et al. (2000): 99.5% w/w flour, and 0.5% w/w NaCl (dry basis % w/w) were added and mixed. The Kansui alkaline salt formulation made up of 0.6% w/w sodium carbonate (Na_2CO_3) and 0.4% w/w potassium carbonate in distilled water. The Kansui formulated mix was added to the dry noodle formulation mix at 36% w/w (of the total dry w/w% formulation) rye and wheat noodle preparations, and 56% (of the total dry w/w% formulation) for the barley formulation. The alkaline noodle formulation and production was performed at the Leslie Research Centre, Queensland Department of Agriculture, Fisheries and Forestry (203 Tor Street, Toowoomba, Queensland 4350, Australia).

2.1.4. Processed food cell wall and solubilised yield (WEAX and WEBG) amounts and percentage calculations

The processed food yield percentages were calculated by subtracting the original flour yield weight (g), from the processed food yield weight (g), then dividing by the original flour weight and converting to a percentage. The WEAX (water extractable AX) yield was calculated from monosaccharide analysis of the solubilised fraction. The solubilised BG yield amounts (WEBG) were calculated by subtracting the WEAX yield (g) differences with the original flour, from the cell wall yield (g) and original flour difference.

2.1.5. Food processing operations

In order to determine the full effects of various food processing operations on the characterisation and functionality of the dietary fibre, the endosperm flours were designed to be the major ingredient (>96% w/w) in the various recipes. Other ingredients were only added so that the food could be produced, for example, the yeast, sugar and salt incorporated into the dough and bread recipes so that that fermentation could take place.

2.1.5.1. Dough fermentation process. The dough and bread procedures were performed using a Panasonic Bread Bakery SD 251