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Particle size of milled barley and sorghum and physico-chemical properties of grain following extrusion

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ABSTRACT

Milled barley and sorghum grains were separated into three size fractions (fine, <0.5 mm; medium, 0.5–1.0 mm; coarse, >1.0 mm) and extruded at two maximum temperatures (100 °C; 140 °C). Mechanical resistance and specific mechanical energy during extrusion was significantly higher for fine fractions, and extrusion at high temperature resulted in higher mechanical resistance. Pressure generated during extrusion was higher for the fine fraction in sorghum but lower in barley. Expansion index was highest for the fine fraction for barley, but did not differ significantly between sorghum fractions or with extrusion temperature. For all samples, extrusion at low temperature resulted in a higher final paste consistency and lower water absorption index, but there was no significant effect on water solubility index (WSI). Fraction size showed a significant effect on WSI in sorghum but not in barley. The results are rationalised in terms of differences in grain composition between sorghum and barley.

1. Introduction

Extrusion cooking is a high temperature, high pressure, short time treatment in which food or feed material is exposed to mechanical shearing (Baik et al., 2004; Lai and Kokini, 1991). The reactions occurring during extrusion are influenced by a large number of variables that are related both to the machine and to the raw materials (Mathew et al., 1999). The effect of different equipment variables (such as feed rate, water addition rate, barrel temperature, screw configuration and screw speed) on rheological and physiochemical properties of the extrudate have been reviewed (Lai and Kokini, 1991). Changing these independent variables can change one or more dependent variable such as mechanical energy input to the extruder, generated pressure and product temperature. As a consequence, independent variables will affect the physico-chemical properties of the melt (Akdogan, 1996; Lai and Kokini, 1991; Whalen et al., 1997) and the physical characteristics of the extrudate (Ryu and Ng, 2001).

Changes in extrusion dependent variables, and thus physico-chemical properties of extrudate, can directly and indirectly influence subsequent application value. In animal feeds, extrusion has been shown to influence animal performance as well as affecting feed processing decisions in industry. For example, specific mechanical energy (SME) input during extrusion has been linked with palatability acceptance by animals (Tran et al., 2008), the relative ease with which a material can be extruded, and the cost of the extrusion operation (Miladinov and Hanna, 2000). The extent of extrudate expansion is one of the most important properties as it influences the porous structure of the extrudate (Plews et al., 2009). Extruded animal feeds often have coatings, such as heat sensitive enzymes and flavours, applied by vacuum, and the efficiency of this process depends on the porosity of the extrudate (Li et al., 2003). Changes in hydration properties such as water absorption index (WAI) and water solubility index (WSI) have been reported to affect both the ability of feed to mix with digestive enzymes and the general behaviour of feed in the digestive tract of monogastric animals (White et al., 2008). In addition, hydration properties and integrity of extrudate have been reported to affect extrudate stability in water which is an important property in fish and aquaculture feeds (Lim and Cuzon, 1994).

Compared with the large body of research on extruder parameters, relatively little research has been conducted into the role of raw material parameters, particularly particle size. The research which has been undertaken into feed material particle size, shows that it influences both extruder operation and extrudate properties (Altan et al., 2009; Carvalho et al., 2010; Garber et al., 1997; Mathew et al., 1999; Onwulata and Konstance, 2006; Zhang and Hoseney, 1998). Different particle sizes have been achieved by changing grain milling screen size (Mathew et al., 1999) to give

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different distributions of particle size (Altan et al., 2009; Garber et al., 1997; Zhang and Hoseney, 1998) or segregation by sieving (Al-Rabadi et al., 2009; Carvalho et al., 2010; Onwulata and Konstance, 2006). Generally, it can be concluded form these studies, that particle size has a significant effect on a wide range of processing variables and hydration properties of extrudates generated. Effects were also dependent on grain fragment pre-conditioning, as well as on particle size and the interaction effect of other extrusion processing variables. Most reported experiments were based on maize as the main starch/grain material.

The objective of the present study was to characterise a range of compositional and functional properties, as well as processing parameters, of separated size fractions after extrusion of two grains that are representative of grains used in animal diets, and which can serve as models of wholegrain extrusion for human foods. Barley was examined as an example of a grain that contains appreciable levels of (soluble) dietary fibre and has relatively low starch content compared to maize. For comparison, sorghum, which is a grain that is high in starch and low in soluble dietary fibre, was also examined. The processing dependent variables during extrusion were torque, specific mechanical energy (SME) and die pressure. The functional property characteristics studied were water absorption index, water solubility index, rheological profile on heating in excess water (paste consistency), and expansion index (EI).

2. Materials and methods

2.1. Materials

2.1.1. Cereals and milling

Barley (variety; Buster) and sorghum (variety; Binalong, PBI Narrabri) were obtained from the Department of Primary Industries and Fisheries (Queensland, Australia). Grains were milled using a hammer mill (HM) (Australian Agriculture Machinery Group, Australia) at a speed of 1140 rpm, with samples of milled grain collected at a constant motor load. Equal portions of each grain were milled through three screen sizes (2, 4 and 6 mm) separately to produce ground material with a range of different particle size distributions. Grains milled through different hammer-mill screen sizes were mixed manually, then sieved using a sieve shaker to produce three particle size ranges: coarse (>1.0 mm), medium (1.0–0.5 mm), and fine (<0.5 mm), in addition to the unsieved ground grain (control). Table 1 shows the particle distribution, average particle size (d_{gw}) and geometric standard deviation (s_{gw}) of the ground barley and sorghum grains after being hammer-milled at three hammer-mill screen sizes and after being mixed. The moisture content of each particle size was determined by drying in a hot air oven (135 °C for 3 h).

Table 1
Fraction yield, average particle size and starch content (±SEM) in ground and segregated grain particles of barley and sorghum.

Grain characteristic	Grain	
	Barley	Sorghum
d_{gw}[a] (mm)	0.684	0.661
S_{gw}[b]	2.11	1.96
Starch content (%)		
Ground (control)	48.23 ± 1.59	63.8 ± 1.48
>1.0 mm	53.60 ± 0.47[c]	69.7 ± 1.42
1.0–0.5 mm	47.7 ± 1.48	64.0 ± 3.04
<0.5 mm	43.0 ± 0.92	63.5 ± 1.72
Sieve opening (mm)	Distribution of particles after sieving (g/l00 g of sample)	
3.35	0[d]	0
2.8	0.12	1.07
1.7	6.67	4.46
1.0	27.50	22.91
0.5	31.57	37.73
0.25	14.67	21.27
0.125	12.30	9.10
0.75	4.81	1.74
Pan	1.08	0.22

[a] d_{gw} geometric mean diameter.
[b] S_{gw} geometric standard deviation and equal to Log normal standard deviation (ASAE, 2003).
[c] Estimated by subtraction of starch content in unsieved ground from starch content in the fine and medium fraction.
[d] Values are duplicate measurements of 100 g sample retained on top of sieves after 29 min shaking.

Table 2
Extruder screw configuration profile.

Screw elements	Number of screw elements and their length in D*	Section length of each type of screw element (mm)
Twin flight feed screw	13 × 1D	208
60° Forward paddle	4 × 0.25D	16
Twin flight feed screw	4 × 1D	64
60° Forward paddle	8 × 0.25D	32
90° Paddle	4 × 0.25D	16
Twin flight feed screw	6 × 1D	80
60° Forward paddle	8 × 0.25D	32
90° Paddle	4 × 0.25D	16
Twin flight feed screw	1 × 0.5D	8
Twin flight feed screw	8 × 1D	128
Single flight feed screw	1 × 1.5D	24
Total	40	640

* D: the extruder barrel diameter; for the Prism Eurolab KX16 D = 16 mm.

2.1.2. Extrusion conditions and processing parameters

High-temperature short-time (HTST) extrusion cooking was conducted using a co-rotating twin-screw model Prism Eurolab KX16 (Thermo Prism, Staffordshire, UK). The screw profile is shown in Table 2. The barrel diameter was 16 mm with a length/diameter ratio of 40:1. The die had two openings each 2 mm in diameter and 8 mm in length. Melt pressure was measured with a pressure transducer fitted to the die block (Terwin, Nottinghamshire, UK). Motor torque, screw speed, barrel temperatures and melt pressure were monitored with Prism software (Sysmac-SCS version 2.2; Omron Corporation, Milton Keynes, UK). Liquid feed rate and dry feed rate were recorded manually after being calibrated before each run. Dry feed was fed through a single screw volumetric feeder (KX16 Powder feeder; Brabender Technologie, Duisburg, Germany). Water was injected through a port 150 mm from the start of the barrel using a peristaltic pump (L/S 7523) with a Tygon Lab tubing 13 (0.8 mm internal diameter, Masterflex; Cole-Parmer Instrument Company, Vernon Hills, IL, USA).

The dry feed rate for barley and sorghum was 20 g/min and 25 g/min, respectively, and the amount of water added at the extruder barrel was adjusted to compensate for moisture differences in the samples to have a dough moisture content of 55% for barley and 50% for sorghum (wb). Barley fractions were extruded at lower feed rate and higher moisture content, compared to sorghum, to avoid any possible blockage during extrusion. Two sets of barrel temperature settings (high and low) (Table 3), and constant screw speed of 200 r.p.m. were used.

Samples were collected when the extruder was running at steady state (i.e. stable values for both torque and die pressure). The samples were collected over 15–20 min, placed in an aluminium tray, and dried in a hot air oven (50 °C for 24 h). After drying, they were sealed into plastic bags and stored at −18 °C pending further analysis.