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Maize bran/oat flour extruded breakfast cereal: A novel source of complex polysaccharides and an antioxidant

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ABSTRACT

A maize bran/oat flour extruded breakfast cereal was developed as a novel source of an antioxidant and complex polysaccharides. Six levels of maize bran/oat flour were formulated (0, 10, 20, 30, 40 and 50%, w/w). The breakfast cereal containing 30% maize bran was the most accepted by consumers. A 100 g serving of this cereal formulation provides 0.2 g of ferulic acid, and 8 g of complex polysaccharides, which includes 1.2 g of β-glucans and 6.8 g of arabinoxylans. This cereal breakfast could be an alternative to maize bran, which is a by-product scarcely used for human consumption.

1. Introduction

To satisfy the demands of increasingly health conscious consumers, many food processors are finding ways to add functional ingredients to their products. The major constituent of cereals is starch. Besides starch, cereals also contain other polysaccharides, known as non-starch polysaccharides, which include arabinoxylans, β-glucans, pectins and arabinogalactans (Fincher & Stone, 1987; Izydorczyk & Biliaderis, 1995), also called dietary fibre. The term dietary fibre is used, collectively, to describe a group of substances in plant material, which resist human digestive enzymes. Such fibres consist primarily of cellulose, hemicellulose, pectin and lignin. Dietary fibres can then be divided into two groups: water-insoluble and water-soluble fractions (Laroche & Michaud, 2007). Soluble fibre has been reported to reduce elevated blood cholesterol, triglyceride, and glucose levels. Insoluble fibre functions as a water-holding-capacity agent, and can reduce intestinal transit time when present in adequate amounts in food (Anderson, 1986). Arabinoxylans and β-glucans, the most important cereal non-starch polysaccharides, are partially water-soluble and have an impact on various food preparations. They are also known to alleviate disease symptoms, such as diabetes, atherosclerosis and colon cancer (Karppinen, Liukkonen, Aura, Forssell, & Poutanen, 2000). Among cereal grains, barley and oats are rich in soluble fibre components, especially β-glucans (37% w/w). These non-starchy polysaccharides are composed of (1 → 3), (1 → 4) mixed linked glucose (Wood, Weisz, & Blackwell, 1994; Wood, Weisz, & Mahn, 1991). Maize bran is a by-product of the commercial maize dry milling process in Mexico. Maize bran contains heteroxylans (approximately 50%), cellulose (approximately 20%) and phenolic acids (approximately 4%, mainly ferulic and diferulic acids) (Carvajal-Millan et al., 2007; Saulnier, Vigouroux, & Thibault, 1995). Ferulic acid (FA) is the predominant phenolic compound in maize bran, and is mainly bound to cell wall polysaccharides (Fry, 1986). Phenolics can act as free radical terminators, chelators of metal catalysts, or singlet oxygen quenchers (Shahidi & Wanasundra, 1992). Consumption of free radicals and oxidation products may be a risk factor for cancer and cardiovascular disease, and dietary phenolics may have health benefits (Huang, Ho, & Lee, 1992). Even though maize bran is a low-cost, food grade cereal fibre and antioxidant source, it is used sparingly as an ingredient in foods.

The purpose of this study was to develop and evaluate a maize bran/oat flour extruded breakfast cereal as a novel source of complex polysaccharides and an antioxidant.

2. Materials and methods

2.1. Materials

Maize bran was supplied by a commercial milling industry in Northern Mexico. Oat flour was provided by Avena de Chihuahua,

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S. A. Sucralose was purchased locally. All chemicals were reagent pure grade. Maize bran and oat flour were milled down to 0.84 mm particle size, using a M20 Universal Mill (IKA®, Werke Staufen, Germany).

2.2. Extruded breakfast cereal preparation

Six levels of maize bran/oat flour were formulated. The maize bran levels used in this study were 0, 10, 20, 30, 40 and 50% (w/w). Duplicate batches (1500 g each) were prepared; 0.06% (w/w) sucralose was added to each blend. For each run, the maize bran/oat flour blend was conditioned to a moisture content of 25%. The material was placed in sealed polyethylene bags and allowed to equilibrate for 12 h at 5 °C and then extruded in a single-screw extruder (Ciatec, Chihuahua). The following extrusion parameters were kept constant: die design, screw speed (140 rpm), and barrel temperature distribution (70 °C, 90 °C, 100 °C, 100 °C, 100 °C). Following extrusion, the product was dried at 60 °C in a forced-air convection oven to ~8% moisture. The extruded materials were milled to 0.84 mm particle size, using a M20 Universal Mill (IKA®, Werke Staufen, Germany), packed in polyethylene bags and stored in a cool room (0 °C) until used.

2.3. Chemical analysis

2.3.1. Proximate analysis

Moisture, crude protein, fat, crude fibre, carbohydrates and total ash were determined using A.O.A.C. approved methods (2002) .

2.3.2. β-Glucan content

The β-glucan content in the ground extruded samples was determined according to the method of McCleary and Glennie-Holmes (1985), using a Megazyme kit (Wicklow, Ireland). The method involves dispersing the samples in a phosphate buffer (4.0 ml, 20 mM, pH 6.5) and incubating with lichenase (EC 3.2.1.73), at 50 °C for 60 min. A second step, with β-glucosidase (EC 3.2.1.21) at 50 °C for 20 min, hydrolyses the oligosaccharides to glucose. Glucose is then derivatized to a coloured substance and analysed spectrophotometrically at 510 nm with a Cary 1E Varian Spectrometer (Varian, St. Helens, Australia).

2.3.3. Arabinoxylan content

Neutral sugars content in the ground extruded samples was determined after hydrolysis with 4 N trifluoroacetic acid at 120 °C for 4 h (Carvajal-Millan et al., 2007). The reaction was stopped on ice and the extracts were evaporated under air at 40 °C, and rinsed twice with 200 μl of water. The evaporated extract was solubilized in 500 μl of water. Inositol was used as internal standard. Samples were filtered through 0.45 μm (Whatman) paper and analysed by high performance liquid chromatography (HPLC), using a Supelcogel Pb column (300 × 7.8 mm; Supelco, Inc., Bellefont, PA) eluted with water (filtered 0.2 μm, Whatman) at 0.6 ml/min and 80 °C. A refractive index detector, Star 9040 (Varian, St. Helens, Australia), was used. Arabinoxylan content was estimated from the sum of xylose + arabinose. A Star Chromatography Workstation system, control version 5.50 was used.

2.3.4. Ferulic acid

Ferulic acid contents in the breakfast cereals were quantified by HPLC after a de-esterification step, as described by Vansteenkiste, Babot, Rouau, and Micard (2004). One-hundred milligram of sample were allowed to react with 1 ml of 2 N NaOH for 2 h in the dark at 35 °C under argon. After adding 3,4,5-trimethoxy-*trans*-cinnamic acid (TMCA, internal standard, 10 μg), the pH was adjusted to 2.0 ± 0.2 with 4 N HCl. Phenolics were extracted twice with diethyl ether, and evaporated at 30 °C under argon. The dried extracts were solubilized in 0.50 ml of methanol/water/acetic acid (40/59/01), filtered (0.45 μm) and injected (20 μl) into the HPLC apparatus using a Supelcosil LC-18-DB (250 × 4.6 mm) (Supelco, Inc., Bellefont, PA) column. Detection was by UV absorbance at 280 nm. Isocratic elution was performed using methanol/water/acetic acid (40/59/01) at 0.6 ml/min at 35 °C. A Varian 9012 photodiode array detector (Varian, St. Helens, Australia) was used to record the ferulic acid spectra. A Star Chromatography Workstation system control, version 5.50, was used.

2.3.5. Antioxidant activity

Antioxidant activity was determined by the FRAP method (Benzie & Strain, 1996). One gramme of extruded sample was mixed with 9 ml of 100 mM phosphate buffer (pH 7.6 containing 0.1 mM EDTA) during 30 min at 25 °C. The mixture was centrifuged (15,000 rpm, 15 min, 25 °C) and the supernatant was used for the measurements. The FRAP reagent was prepared by mixing 30 mM acetate buffer (pH 3.6), 40 mM TPTZ (2,4,6-tripyridyl-*s*-triazine) and 20 mM $FeCl_3$ in a ratio of 10:1:1 (v/v). In total, 100 μl of sample supernatant, 300 μl of distilled water and 3 ml of FRAP reagent were pipetted into test tubes and incubated at 37 °C for 4 min. Each sample was run in triplicate. An aqueous solution of known Fe(II) concentration was used for calibration (in a range of 100–1000 μM). A Cary 1E Varian UV–Visible Spectrophotometer (Varian, St. Helens, Australia) was used to measure absorbance at 593 nm.

2.4. Physical analysis

2.4.1. Water absorption index (WAI) and water solubility index (WSI)

WAI and WSI were determined as outlined by Anderson, Conway, Pfeifer, and Griffin (1969). A 2.5 g sample of ground product was suspended in 30 ml of water at 30 °C, in a 50 ml pre-weighed centrifuge tube, stirred intermittently over a 30 min period, and centrifuged at 3000 rpm for 10 min. The supernatant liquid was carefully poured into a pre-weighed evaporating dish. The remaining gel was weighed and the WAI was recorded as the gel weight (g)/dry sample weight (g). The amount of dried solids recovered by evaporating the supernatant from the water absorption test was expressed as a percentage of dry solids in the 2.5 g sample and defined as the WSI. Assays were performed in triplicate.

2.4.2. Colour

Ground extruded samples were analyzed with a colour difference meter (model CR-300, Minolta, Japan). Lightness (*L*), redness (a), and yellowness (b) values were recorded. Each value was an average of ten different independent measurements.

2.4.3. Breaking strength

Breaking strength of the non-ground extruded samples was determined with the TA-XT2 Texture Analyzer (Texture Technology Corp., Scarsdale, NY, USA), based on the method of Onwulata, Konstance, Strange, Smith, and Holsinger (2000). A cylinder probe (3 mm radius) attached to the arm of the analyzer was used to compress the sample at a constant speed of 0.2 mm/s against the flat plate fixed on the loading frame. The sample was compressed to 60% of the original height. Ten replications were conducted for samples from each treatment.

2.5. Sensory evaluation

A hedonic scaling method, coupled to a verbal concept seven-point scale (7 = like very much, 1 = dislike very much), was used to estimate quality (colour, flavour, texture, and general acceptability) of the extruded products. Treatments with the lowest breaking strength (30% and 40% maize bran) were selected for sen-

sory evaluation. The taste panel consisted of 30 untrained panellists (Larmond, 1977).

2.6. Statistical analysis

Data were analyzed with an ANOVA. Means separation was according to Tukey ($p \leqslant 0.05$) (MINITAB 13 version).

3. Results and discussion

3.1. Chemical analysis

3.1.1. Proximate composition

The proximate composition of maize bran/oat flour extruded cereal is shown in Table 1. Moisture, protein, fat and ash contents significantly decreased from 9.8% to 6.3%, from 13.0% to 9.8%, from 5.8% to 3.1% and from 2.4% to 2.3%, respectively, as the maize bran content in the sample increased from 0% up to 50%. On the contrary, significant increases in crude fibre and carbohydrate contents from 0.7% to 6.3% and from 68% to 72%, respectively, were observed when the maize bran content in the extruded material changed from 0% up to 50%. The moisture content was similar to that reported in other extruded mixtures, while protein, fat and ash levels were lower (Obatolu, 2002). There were no significant differences between the levels of ash in the samples.

3.1.2. β-Glucans and arabinoxylans

β-Glucan contents decreased from 2.3% to 0.7% (w/w) and arabinoxylan contents increased from 0.2% up to 22% (w/w) as the maize bran content changed from 0% to 50% (w/w) (Fig. 1). Therefore, a 100 g serving of the breakfast cereal containing 30% maize bran, which was the most accepted by consumers, provides 8 g of complex polysaccharides (1.2 g of β-glucans and 6.8 g of arabinoxylans). The recommended daily allowance (RDA) of dietary fibre is 20–35 g/d according to the dietary reference intakes for energy, carbohydrate. The FDA was one of the first national agencies to recognize a role for fibre in cardiovascular disease risk reduction. Products that contain 0.75 g β-glucans, or 1.78 g Psyllium per serving, are permitted to carry a health claim stating that the product "will reduce the risk of coronary heart disease".

Table 1
Proximate composition of maize bran/oat flour extruded breakfast cereal

Maize bran/oat flour level(%, w/w)	Moisture	Protein	Fat	Ash	Crude fibre	Carbohydrates
0	9.8a	13.0a	5.8a	2.4a	0.7f	68.3b
10	8.8a	12.1b	5.1b	2.4a	1.7e	69.9b
20	6.4c	11.8b	4.6c	2.4a	2.9d	72.0a
30	7.7b	11.5b	3.9d	2.3b	4.1c	70.4a
40	6.3c	11.2b	3.3e	2.3b	5.3b	71.6a
50	6.3c	9.8c	3.1e	2.3b	6.3a	72.3a

Mean values in the same column with different letters are significantly different ($p < 0.05$).

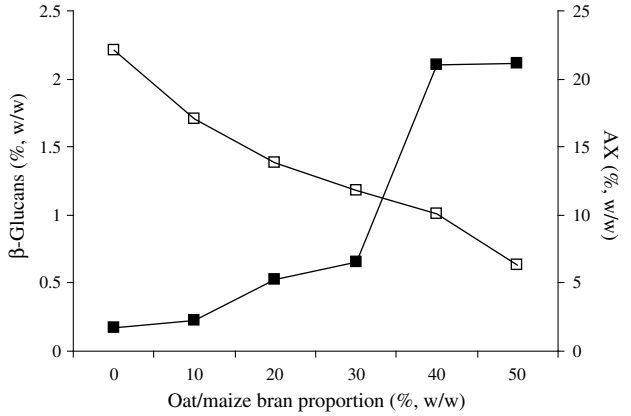

Fig. 1. β-Glucan (□) and arabinoxylan (■) contents of maize bran/oat flour extruded breakfast cereal.

3.1.3. Ferulic acid and antioxidant activity

Ferulic acid content in the maize bran/oat flour breakfast cereal increased from 0.2 to 2.5 mg/g as the maize bran level changed from 0% to 50% (w/w) (Fig. 2). A 100 g serving of the breakfast cereal containing 30% maize bran, which was the most accepted by consumers, provides 0.2 g of ferulic acid, which is 20% of the IDR for adults. Baublis, Lu, Clydesdale, and Decker (2000) produced a wheat-based breakfast cereal as a source of antioxidants, finding that ferulic acid had a strong antioxidant capacity. This cereal presented a ferulic acid content of 0.74 mg/g cereal, which is less than half of the ferulic acid content in the sample containing 30% of maize bran (2 mg/g cereal). The antioxidant capacity in this cereal is similar to that of ascorbic acid, α-tocopherol or uric acid, which is around 2.0 mmoles Fe^{++} (Benzie & Strain, 1996). The medicinal action of ferulic acid is mainly due to its antioxidant capacity, free radical-scavenging, and chelation of redox-active metal ions. The total polyphenol intake can be calculated from the polyphenol contents in food and food consumption tables. Kühnau (1976) determined a flavonoid intake in the United States of ~1 g/d. Although, ferulic acid is heat-labile and some loss was expected during extrusion, the cereals with lower percentage of maize bran had 6.5% of ferulic acid recovery, and samples with a higher percentage of maize bran had a recovery of approximately 22%. The latter evidence suggests that maize bran protects ferulic acid from heat damage.

3.2. Physical analysis

3.2.1. WAI and WSI

For the different extruded samples, an increase in the maize bran content resulted in higher WAI values (Table 2) which can be explained by the fibre high water absorption capacity. These results are similar to those reported by Hashimoto and Grossmann (2003). WSI showed a slight increase, which can be the result of starch damage during extrusion due to high temperature, as found by Likimani, Sofos, Maga, and Harper (1991).

3.2.2. Colour and breaking strength

Colour L^* value decreased as more fibre was added to the extrudates; the values ranged from 80 to 76 (Table 2). These values are lower than those that have been reported in corn flakes (Lajoie,

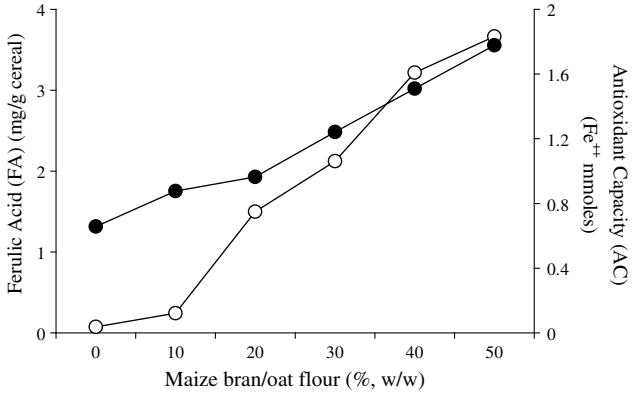

Fig. 2. Ferulic acid (○) content and antioxidant capacity (●) of maize bran/oat flour extruded breakfast cereal.

Table 2
Maize bran/oat flour extruded breakfast cereal physical characteristics

Maize bran/oat flour level (%, w/w)	WAI	WSI	L^*	Breaking strength (N)
0	349a	3.3a	80.5a	101a
10	364a	4.3a	80.5a	90a
20	370a	4.1a	80.4a	91a
30	383a	5.0a	78.4b	78a
40	389a	5.7a	76.9c	75a
50	413a	5.6a	76.6d	119b

Mean values in the same column with different letters are significantly different ($p < 0.05$).

Table 3
Sensory qualities of maize bran/oat flour extruded breakfast cereal

Maize bran/oat flour level (%, w/w)	Colour	Taste	Texture	Overall acceptability
30	5.4a	5.7a	5.5a	5.5a
40	5.0a	5.4a	4.9b	5.1a

Mean values in the same column with different letters are significantly different ($p < 0.05$).

Goldstein, & Geeding-Schild, 1996). Samples with little maize bran presented a high breaking strength, due to the low expansion capacity of oat (Table 2) Samples with higher levels of maize bran presented a high breaking strength, due to the smaller expansion when incorporating high levels of fibre. These results are similar to those reported by Hashimoto and Grossmann (2003).

3.3. Sensory evaluation

Treatments with the lowest breaking strength (30% and 40% maize bran) were selected for the sensory evaluation. Sensory quality is shown in Table 3. The colour, taste, texture and general appearance had higher scores for 30% maize bran formulation.

4. Conclusions

The results showed that maize bran can be used in the preparation of extruded breakfast cereal at moderate levels (substitution of 30% of the oat flour). This maize bran/oat flour extruded breakfast cereal contains several compounds that could be beneficial to health. Among these compounds, β-glucans and arabinoxylans are a significant source of fibre, while ferulic acid provides a strong antioxidant activity. A 100 g serving of this cereal formulation provides 0.2 g of ferulic acid, and 8 g of complex polysaccharides, which includes 1.2 g of β-glucans and 6.8 g of arabinoxylans. These results suggest that maize bran/oat flour cereal formulations could be an alternative to maize bran, which is a by-product scarcely used for human consumption.

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