PUFFING AND JET COOKING AFFECT SOLUBILITY AND MOLECULAR WEIGHT OF BARLEY β-GLUCANS

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ABSTRACT

Foods containing barley or oats are often marketed as healthy because of the dietary fiber (1→3) (1→4)-β-D-glucan. Processing conditions can affect the molecular structure of these dietary fibers, which in turn affect quality and properties of the products. In this study, the effect of puffing and jet cooking conditions on changes in the solubility and molecular weight of barley β-glucans was investigated. Barley flour was processed in a pasta extruder to produce particles similar in size and shape to rice. These particles were puffed at 230, 250 and 270°C for 6, 8 and 10 s in a rice cake machine. Solubility and molecular weight of barley β-glucans were determined by using water extracts (25 or 65°C). The amount of β-glucan extracted in water at 25°C increased from 41.1% in cakes puffed at 230°C/6 s to 69.7% in cakes puffed at 270°C/10 s. The amount of β-glucan extracted in water at 65°C increased from 63.6% in samples puffed at 230°C/6 s to 99.1% in samples puffed at 270°C/10 s. The molecular weight of β-glucans in barley was reduced by puffing and jet cooking treatments.

INTRODUCTION

In the last few years, attention has been directed toward improving the nutritional and health value of expanded snacks by including grains rich in (1→3) (1→4)-β-D-glucan such as oats and barley. There is evidence indicating that foods containing β-glucans lower blood cholesterol and affect blood

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glucose concentration (Kahlon et al. 1993; Wang et al. 1993; Hallfrisch et al. 1995; Peterson 1995; Liljeberg et al. 1996; Knuckles et al. 1997; Yokoyama et al. 1998; Bourdon et al. 1999). The soluble portion of the β-glucan, rather than the total β-glucan content in the food, is most responsible for lowering serum cholesterol and blood glucose levels (Izydorczyk et al. 2000).

Several different processing methods are used commercially to produce expanded rice, corn and wheat snacks. Continuous hot-air puffing is a common technique used by industry to puff cereal grains. Puffed cereal snacks are usually made from whole or slightly modified grain. Some grains like rice and corn puff readily, producing high volume cereal foams (Hsieh et al. 1989, 1993; Huff et al. 1992). Lee et al. (1999) indicated that pearled barley could be puffed in a manner similar to rice in a rice-popping machine.

Harsh processing conditions that generate high shear and temperature such as extrusion processing reduce the molecular weight (MW) of β-glucans (Wen et al. 1990; Knuckles et al. 1998). Puffing may be less damaging to food molecules than extrusion processing which utilizes a considerable amount of mechanical shear in addition to heat. Lee et al. (1999) observed that the total β-glucan content of puffed barley cakes was similar to that measured in the starting material. Jet cooking is another processing method common to the food industry that subjects the food material to harsh conditions of heat, shear and pressure. Jet cooking is used in the preparation of starch/oil composites and for encapsulation of flavors (Fanta and Eskins 1995; Fanta et al. 1999; Klamczynski et al. 2002). Knuckles et al. (2002) demonstrated that jet cooking decreased the MW of oat β-glucans. The objective of the present study was to determine how the puffing and jet cooking conditions will affect the solubility and MW of barley β-glucans.

**MATERIALS AND METHODS**

**Puffed Cakes**

Commercial barley flour was purchased from a local supplier (Giusto’s Specialty Foods, South San Francisco, CA). Barley flour (300 g) was suspended in water (2700 g), heated to 90°C, kept at this temperature for 10 min with constant stirring and then cooled to 50°C. This cooked barley flour was used for preparation of a dough that was fed into a pasta extruder to produce rice-like particles. The dough used for preparation of barley flour particles was prepared by mixing 360 g of cooked and 670 g of uncooked barley flour with a Hobart mixer (model A-200, Hobart, Troy, OH). The mixing time was 60 s at speed 1. The dough was extruded by using pasta machine (model LAB 2V36, Ambrette Machinery Corp. New York, NY) through die openings
shaped like rice grains and chopped into particles similar to short grain rice in size and shape. Formed particles were dried in a hot air oven (65°C) to final moisture content of 12% (w/w) to minimize activity of enzymes present in the barley flour and extend the acceptable storage period. The particles were conditioned 24 h before puffing to 18% moisture content as per AACC method 26–95 (AACC 2000).

The conditioned particles (20 g) were puffed by using a rice-popping machine (model 1, Airin, Co., Okazaki, Japan). The platen surface temperature was adjusted to 230, 250 and 270°C for 6, 8 and 10 s. Each puffed cake was about 10 cm in diameter with a thickness ranging from 2 to 5 mm. Each cake was put in a plastic bag (zip-lock type) and stored at room temperature until the analyses were performed.

Jet Cooking

Barley flour (5% w/w) was blended with water before jet cooking (Hydro-Thermal, model M 103, Waukesha, WI). The steam pressure was maintained at 65–68 psi, and backpressure on the pump and holding tube was 30 psi. Flow rate was adjusted to 3.5 L/min, the cooking temperature was maintained at 102°C or 112°C ± 0.5°C, and total cooking (residence) time was 90 s. Cooking temperatures were selected based on preliminary experiments. Cooked samples were collected in stainless trays, cooled to room temperature, frozen and freeze dried.

β-Glucan Analyses

The β-glucan content was determined according to the method of McCleary and Glenie-Holmes (1985) using a Megazyme kit (Wicklow, Ireland). Molecular weight was determined by high performance size exclusion liquid chromatography with multiple angle laser light scattering detection (Wyatt 1993) and reported as weight average MW. Samples for MW determinations were prepared by using finely ground (cyclone mill equipped with a 0.5 mm screen, UDY Corp. Fort Collins, CO.) samples of barley flour cakes heated in dimethylsulfoxide (0.5 mL) for 15 min, diluted with water (2.5 mL) and shaken for 1 min. Salivary alpha amylase (60 U) was added, and the samples were incubated at 40°C for 75 min, filtered (0.45 μm) and injected in the HPLC column. The data were analyzed as described by Knuckles et al. (1997). The HPLC system consisted of an in-line degasser (Degasys DG-1200, Rannin, Woburn, MA.); HP 1050 series autosampler and two pumps (Hewlett Packard, Palo Alto, CA.); columns (fractionation range to 20 million Da); UV/VIS spectrophotometer (1040 M, Hewlett Packard); Dawn DSP-F multiple angle laser light scattering (LS) detector (Wyatt Technology Corp., Inc., Santa Barbara, CA.); and differential refractive index (RI) detector (model 401,
Column sequence was: guard (Waters, Millipore Corp.), PL Aquagel-OH 60 (7.5 × 300 mm, Polymer Laboratories) and Waters Ultrahydrogel 2000 (13 μm, 7.8 × 300 mm), 500 (10 μm, 7.8 × 300 mm), and 250 (6 μm, 7.8 × 300 mm). Mobile phase (0.02% NaN₃) was pumped at 0.5 mL/min. Columns and detector were maintained at 35°C.

The results are presented in a graph where dW/d(log M) exhibits the quantity of material that is contained in any molecular fraction interval.

β-Glucan Solubility

Samples (2.0 g) of barley flour cakes were ground with a UDY mill fitted with a 0.5 mm screen. The ground samples were dispersed in 2.0 mL of 50% aqueous ethanol followed by 20 mL water using a vortex mixer. The samples were incubated in a water bath (25 or 65°C for 60 min) and then centrifuged (3000 × g) for 30 min. Soluble β-glucan was determined in the supernatant and expressed as a percentage of the total β-glucan content determined in unpuffed barley particles.

Experimental Design

A completely randomized design was used in the experiment. The variables were puffing temperature (230, 250 and 270°C) and puffing time (6, 8 and 10 s). All determinations were made at least in duplicate and analyzed by using analysis of variance (ANOVA, SigmaStat, SPSS Inc., Chicago, IL). F-tests were used to determine significant differences (P ≤ 0.05). Jet-cooked samples were analyzed in three replications at each cooking temperature. All comparisons were made to the unpuffed barley particles.

RESULTS AND DISCUSSION

Puffed Cakes

It is unlikely that puffed cakes made entirely of barley flour would be of commercial interest. The puffed cakes were hard, tough and exhibited a darker color than the unpuffed barley flour particles. Also, at high processing temperatures and longer processing times some samples tended to stick to the platen of the rice cake popper, necessitating the incorporation of release agents to facilitate cake release.

Beta-glucans in the unpuffed barley particles and in puffed cakes ranged in MW from approximately 100,000–1000,000 g/MW (Fig. 1). Puffing lowered the MW of the β-glucans, with the greatest change occurring at higher temperatures. Likewise, the average MW of the β-glucans was smaller for
puffed than for unpuffed particles (Table 1). The smallest decrease in MW tended to occur in samples puffed at low temperature for a short time (230C/6 s), and the largest decrease in MW occurred in samples puffed at high temperature for a longer time (270C/10 s). The data suggest that both puffing temperature and puffing time resulted in a decrease of the average MW of barley β-glucans. The correlation coefficients between temperature and MW ranged from −0.60 to −0.98 (P ≤ 0.05), while correlation coefficients for puffing time versus MW were also generally negative with greater variability.

Both puffing temperature and puffing time increased the solubility of barley β-glucans in water (Table 1). Correlation coefficients for the solubility and puffing temperature ranged from 0.98 to 0.99 (P ≤ 0.05) in samples extracted at 25C and from 0.95 to 0.99 (P ≤ 0.05) in samples extracted at 65C. Correlation coefficients between solubility and puffing time ranged from 0.82 to 0.97 (P ≤ 0.05) in samples extracted at 25C and from 0.93 to 0.99 (P ≤ 0.05) in samples extracted at 65C. The only exception was the sample puffed at 230C/6 s and extracted at 65C, where the correlation was smaller because of experimental error.

**Jet-Cooked Flour**

The MWs of barley β-glucans decreased because of the jet cooking process (Table 1). The average MW of barley β-glucans in flour jet cooked at
112C was similar to the average MW of those cooked at 102C. The MWs of jet-cooked β-glucans were similar to the MWs of those in puffed cakes. Higher solubility of barley β-glucans was observed in samples kept at 65C than in samples kept at 25C in both puffed and jet-cooked samples. The results for both puffed and jet-cooked samples are consistent with earlier research reporting that the MW of oat β-glucans was decreased by heating (~100C) in water for extended periods (2 h), and by jet cooking and autoclaving (Knuckles et al. 1998; Wang et al. 2000).

Interestingly, jet-cooked barley flour did not darken during processing and maintained its light color after jet cooking. This result may be explained by the arrest of polyphenol oxidase (PPO) activity during jet cooking, although determination of PPO activity was not in the scope of this study.

**CONCLUSIONS**

Puffing and jet cooking processes decreased the molecular weight and increased the solubility of barley β-glucans. Although greater amounts of β-glucans in solution may contribute to increased viscosity, decreases in MW may be a moderating factor affecting potential nutritional properties. Recommendations for commercial production of puffed barley cakes should not be
forthcoming without studies of processing conditions to improve cake formation, sensory qualities and nutritional qualities. Puffed products made entirely of barley flour may not be commercially viable, but products made from a blend of barley flour with other starches may improve nutritional value. The use of barley flour in jet-cooked products may also improve the nutritional value of the resulting food products. Extremely fast heat transfer during the jet cooking process may help in the prevention of β-glucan degradation as well as formation of color/flavor components, resulting in appealing and health-promoting barley products.

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