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Comparative studies on physicochemical properties of raw and hydrolyzed oat β-glucan and their application in low-fat meatballs

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ABSTRACT

Oat β-glucan and its hydrolyzates were used as fat replacers in the production of meatballs. The physicochemical properties of raw (OG) and hydrolyzed oat β-glucan (OGH), as well as their application in meatballs were studied. The average molecular weight of OG and OGH was determined by high performance size exclusion chromatography (HPSEC) and was found that OGH decreased from 6.6×10^6 Da to 9.4×10^5 Da (OG) after 1.5 h of enzymatic hydrolysis at 55 °C and pH 5.5 using a cellulase dose of 76 U/g. Dynamic light scattering (DLS) analysis was applied to measure the size distribution of OG and OGH. The mean diameters of OG and OGH were 126.6 nm and 110.3 nm, respectively. The apparent viscosity of OG and OGH was studied at different concentrations (0.5%, 1.0%, 3.0%) and shear rates ($1-300^{-1}$). Both OG and OGH had shear-thinning behavior and OGH exhibited a small decrease in the apparent viscosity. Differential scanning calorimetry (DSC) results showed that OGH and OGH-added meatball (OGHM) had larger T_p than those of OG and OG-added meatball (OGM), respectively. SEM images of OGHM exhibited a more smooth surface than blank meatballs. Textural analysis and sensory evaluation results indicated that the OGH added with 10% fat-rich meatball showed the highest overall acceptability among the meatball samples, therefore oat β-glucan hydrolyzates are very promising dietary fiber source used as fat replacer in traditional meatball production.

1. Introduction

In recent years, obesity has been rising dramatically and reached epidemic levels in some developed countries, leading to a variety of human diseases, such as cardiovascular disease, diabetes, and cancer (Bastien, Poirier, Lemieux, & Després, 2014; Hsu & Chung, 2001; Kratz, Baars, & Guyenet, 2013). Over the past 30 years, there has been increasing interest in the development of low-fat or fat-free products (Rodarte, Biliaderis, Vamvakas, & Zerfiridis, 2004). People are motivated to consume low-fat meat products in order to control caloric intake, reduce the risk of obesity-related diseases and ensure overall body health. However, although the market of the low-fat meat products has been rapidly growing, it still possess a small proportion of the sales of the traditional full-fat meatball products. This was attributed to the inferior texture, appearance, flavor and aroma usually occurred in low-fat meat products, such as meatball, sausage and so on, compared to the high-fat products. The challenge in working with low-fat meat products is related to the reason that the fat globule network would either be disrupted and this could lead to inferior texture of the product (Bengtsson, Montelius, & Tornberg, 2011; Hsu et al., 2001; Petersson, Godard, Eliasson, & Tornberg, 2014).

Many research efforts have been done to develop low-calorie and calorie-free fat replacers, such as cereal polysaccharides, mono-diglycerides, microparticulated protein, patato maltodextrin, Raftiline® (inulin), Simpless® (a blend of microparticulate whey proteins and emulsifiers) and polydextrose (Guven, Yasar, Karaca, & Hayaloglu, 2005; Lee, Inglett, Palmquist, & Warner, 2009; Tamime, Kalab, Muir, & Barrantes, 1995; I. Yılmaz, 2005). Among them, the mixed linkage (1 → 3, 1 → 4)-β-glucans from cereals grains have been widely studied because they are shown to have several health benefits, including the attenuation of blood glucose levels (Lan-Pidhainy, Brummer, Tosh, Wolever, & Wood, 2007; Susan M Tosh, Brummer, Wolever, & Wood, 2008), the reduction of serum cholesterol levels (Braaten et al., 1994), and the improvement of pancreatic and bowel functions (Wrick et al., 1983).

In particular, oat β-glucans out of various dietary fibers has been considered as a ingredients in health-promoting functional

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foods not only because of their health benefits, but also because of their ability to bind water and increase apparent viscosity (Lazaridou, Biliaderis, & Izydorczyk, 2006). Wood et al. (J Wood et al., 1994) and Rimm et al. (Rimm et al., 1996) have been reported that oat β-glucan reduces post-prandial blood glucose and blood cholesterol levels. Furthermore, İ. Yılmaz and Dağlıoğlu (2003) replaced fat of meatballs with oat bran and found that there was no significant difference among the meatball samples with respect to sensory properties, and all samples had high acceptability. Piñero et al. (2008) further evaluated the effect of adding oat β-glucans on physicochemical and sensory traits of low-fat beef patties and suggested that oat soluble fiber cound be successfully as a fat replacer in low-fat beef patties. These benefits provided the potential to develop new low-fat foods containing oat β-glucan.

Nevertheless, the applications of β-glucan are still limited to cereal-based baked foods due to its unique rheological properties such as high viscosity (Bae, Lee, Kim, & Lee, 2009). Since the molecular weight of β-glucans is a crucial characteristic affecting the physicochemical properties including viscosity and functionality in food systems and human health (Mikkelsen et al., 2010), Several researchers have studied the alterations in the molecular weight and structure of β-glucans modified by acid or enzymatic hydrolysis and so on (Gamel, Abdel-Aal, Ames, Duss, & Tosh, 2014; Tao, Zheng Biao, Zheng Yu, & Hai Ning, 2008; Wu et al., 2006), as well as their effects on the physicochemical, rheological and functional properties of oat β-glucans (de Moura et al., 2011; Lazaridou & Biliaderis, 2004). Detailed knowledge about structure/function relationships of oat β-glucans and their hydrolyzates in fat-containing food systems is apparently required in order to explore the full health beneficial properties of this important dietary fiber.

Therefore, the objective is to conduct comparative spectroscopic, chromatographic and rheological studies on the physicochemical properties of unhydrolyzed and hydrolyzed oat β-glucan samples. Special interest in oat β-glucan and its hydrolyzates was the textural analysis and sensory evaluation to study the effect of oat samples on the processing characteristics of meatballs.

2. Materials and methods

2.1. Sample preparation

Naked oat bran was purchased from Yan Bei Food Factory (Wanquan County, Hebei Province, China). Unhydrolyzed oat β-glucan (OG) was prepared as described in our previous work (Zhang, Bai, Bian, & Zhao, 2010). Considering the production cost, a low molecular weight oat β-glucan hydrolyzate (OGH) was prepared for use in pork meatballs by hydrolyzing the unhydrolyzed oat β-glucan with a commercial cellulase (76 U/g, Tianjin Noao Sci&Tech Development Co., Ltd, Tianjin, China) in distilled water (1 mg/mL, 55 °C, pH 5.5) for 1.5 h. The chilled fresh pork meats were transported to the local meat packer in the morning with temperature below −8 °C after slaughtering and meat handling overnight. The pork meats were purchased from the local meat packer and ground with a meat chopper fitted with a plate of 15 mm diameter holes. The ground meat was packaged in plastic bags, and stored at −20 °C for use within a month.

The base ingredients with different ratios of lean pork and pork back fat (80%: 20%, 85%: 15%, 90%: 10%, 95%: 5%, and 100%: 0%) were prepared for the meatballs, in order to study the effects of adding OG and OGH and to be able to compare if adding oat β-glucan or its hydrolyzate could result in similar products as the ones with higher fat or lower fat content. 0.6% OG or OGH was the optimal amount to be added in meatballs by single-factor experiment and sensory evaluation (shown in Fig. S1). Other ingredients included 15% starch, 2.5% NaCl, 1% sugar, 0.1% polyphosphate, 0.1% monosodium glutamate, 0.2% pepper and 0.2% five spice powder. The main ingredients of five spice powder (68 g) were 20 g pepper, 20 g star anise, 10 g fennel seeds, 10 g cinnamon, and 8 g cloves. Meatballs were manufactured according to the processing method, as previously described (Hsu & Chung, 2001), with some modifications. The products were simmered at 85 °C for 20 min and water-cooled to room temperature for textural and sensory analysis.

2.2. Dynamic light scattering (DLS)

The effective hydrodynamic diameter (D_h) and size distributions of OG and OGH were measured using a BI-200SM DLS system (Brookhaven Instruments Corporation, New York, USA) equipped with a MGL-III model 100 mV He–Ne laser (λ = 532 nm), a computer-controlled BI-200SM goniometer, and a BI-9000AT digital correlator. Light scattering was monitored at a 90° angle and the temperature of the sample holder was controlled at 25 °C via a recirculating water bath. Sample solutions (0.5 mg/ml) were carefully filtered through a 0.45 μm membrane directly into a borosilicate glass tube and measured within 5 min. The size distribution (1–1000 nm) of species in the OG or OGH solution was obtained using the CONTIN model.

2.3. High performance size exclusion chromatography (HPSEC)

Molecular weight (M_w) and polydispersity (P_d) determinations for OG and OGH were determined using a HPSEC system equipped with a RID-10A refractive index detector (Shimadzu Scientific Instruments Inc., Kyoto, Japan) and a OHpak SB-804HQ column (8.0 × 300 nm, 10 μm, Shimadzu Scientific Instruments Inc., Kyoto, Japan) placed in a 30 °C column oven. Prior to measurement samples (1% w/v) were dissolved in ultrapure water with 5 mM NaN_3 for 30 min at 80 °C and filtered through 22 μm filtrates. Ultrapure water with 5 mM NaN_3 at a flow rate of 0.8 ml/min was used and sample injection volume was 20 μl. The column was calibrated with dextran standards (M_w: 670, 410, 80, 50, 25, 12, and 5 kDa) from Sigma Chemical Co. (St. Louis, MO, USA). A calibration curve was obtained by plotting the elution volume of dextran standards versus the log of the M_w, $r^2 > 0.999$. The molecular weights of OG and OGH were calculated from the calibration curve.

2.4. Rheology

Rheological properties of OG and OGH were taken using a Haake MARS III rheometer (Thermo-Scientific, Germany) fitted with cone-plate geometry (cone angle of 1°, 35 mm diameter). The measurements were carried out using a gap distance of 1 mm. The temperature was controlled at 25 °C. A dependence of apparent viscosity on shear rate was observed in controlled rate mode. The shear rate was linearly increased from 0.1 to 300 s^{-1}. The experimental data were fitted by a power law constitutive equation (Aziznia, Khosrowshahi, Madadlou, & Rahimi, 2008)

$$\eta = K\gamma^{n-1} \quad (1)$$

where η is the apparent viscosity (Pa s); K is the consistency coefficient (Pa s^n); γ is shear rate (s^{-1}); n is the flow behavior index (dimensionless) describing the divergence from the Newtonian model, $n < 1$ for a shear-thinning fluid and $n = 1$ for a Newtonian fluid. The data of rheological measurements were analyzed using the Rheowin Data Manager Version 4.30.