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Preparation and functional properties of protein from heat-denatured soybean meal assisted by steam flash-explosion with dilute acid soaking ☆

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ABSTRACT

The combined pretreatment of heat-denatured soybean meal using steam flash-explosion (SFE) with sulfuric-acid soaking was investigated to prepare protein from soybean meal. When soybean meal was pretreated by SFE at 1.8 MPa, 2.2 MPa for 8 min and at 2.0 MPa for 8 min and 10 min, combined with 0.9% sulfuric-acid soaking, the extraction yield of protein increased to 67.72%, 70.54%, 69.47% and 71.21% respectively, compared to untreated soybean meal. Scanning electron micrograph of pretreated samples showed the structural disruption of soybean meal. After pretreatment, the protein yield was improved, while protein content of soy protein isolate (SPI) decreased slightly. The functional properties of SPI from pretreated soybean meal were all improved compared to untreated soybean meal and the relationship between functional properties and the changes of surface hydrophobicity of SPI was discussed. The emulsification properties and fat-binding capacity of pretreated SPI were superior to those of SPI prepared from white flakes.

1. Introduction

Soybean meal contains approximately 50% protein. In soybean oil extraction, soybean specially undergoes high-temperature thermal processing for removal of solvent resident and deactivation of anti-nutritional factors (Refstie et al., 2005). Thermal processing denatures and insolubilizes soy protein rendering it poorly functional in foods. If the heat-denatured soybean protein could be refunctionalized, the more benefits of soybean meal can be realized. However, the extraction of high protein yields from high-temperature treated soybean meal is greatly difficult, due to protein denaturation and its location inside the soybean structure. Enzymatic treatment can acquire high protein extraction yield (89–94%) from heat-treated soybean meal (Fischer et al., 2001), but most proteins are converted into peptides and amino acids, resulting in loss of functions for application. Hydrothermal cooking (HTC) and alkali-HTC can increase the extraction of protein from extruded-expelled soybean meal (Wang et al., 2004, 2005). Subcritical water hydrolysis has achieved 46.98% of original protein from soybean meal (Watchararuji et al., 2008). Nevertheless, these methods are based on violent conditions, leading to protein degradation and the loss of processing function.

Steam flash-explosion (SFE) is an innovative method for pretreatment of biomass. This method is based on exposing the biomass to high-temperature pressurized steam and forcing the steam into the tissues and cell of biomass, followed by explosive decompression completed in millisecond (Yu et al., 2012). During the explosion, most of the steam and hot liquid water in the biomass quickly expands and breaks free of the structure. In the previous publication, the results showed that SFE could significantly improve the extraction yield and functional properties of protein from heat-denatured soybean meal (Zhang et al., 2013). However, the particle size of soybean meal must pass through a 20-mesh screen, but not a 80-mesh screen, which limit the application of SFE. It is found that when stem pressure and residence time exceed

Abbreviations: SPI, soy protein isolate; WFs, white flakes; SFE, steam flash-explosion; HTC, hydrothermal cooking; SEM, scanning electron microscopy; ANS, 1-anilino-8-naphthalenesulfonate; SDS, sodium dodecyl sulfate; EAI, emulsifying activity index; ESI, emulsion stability index; FBC, fat-binding capacity; FC, foaming capacity; FS, foaming stability; ANOVA, analysis of variance; LSDs, least significant differences.

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1.8 MPa and 120 s, the protein extraction of soybean meal reached plateau, despite the higher pressure and time. The improvement of mechanical shearing force and tissue damage of soybean can solve the above-mentioned problem.

Dilute sulfuric acid pretreatment is an effective and inexpensive way of hydrolyzing hemicellulose, reducing cellulose crystallinity, and increasing surface area and pore volume of the substrate (Fang et al., 2011). A few available researches demonstrated that the acid treatment influences the structure and function of soy glycinin and SPI (Wagner and Guéguen, 1999a, 1999b). The improvement of functional properties of acid-modified soy proteins was due to their decreased molecular size, and increase in surface hydrophobicity induced by deamidation (Wagner and Guéguen, 1995).

Based on the above viewpoint, a combination of SFE and dilute-acid pretreatment can simultaneously influence the organic tissue and protein structure of soybean meal. The purpose of this work was to define the optimal conditions in which maximum protein extraction yield would be obtained. In addition, the functional properties of protein were also investigated.

2. Materials and methods

2.1. Materials

Soybean meal (protein content 49.49%) was provided by Hangzhou Venus Biological Nutrition Co., Ltd. (Hangzhou, China) with nitrogen solubility index (NSI) of 18.90%. The soybean meal was obtained from dehulled flaked soybeans by extracting oil with hexane and then desolventizing the defatted flakes by means of high-temperature thermal processing. The samples were ground to pass through a 20-mesh screen. The white flakes (WFs) defatted by solvent extracted and desolventized by means of flash- or downdraft-desolventizing to minimize protein denaturation, was purchased from Harbin High Tech (GROUP) Co., Ltd. (Harbin, China) to serve as reference for determination of functional properties. All other reagents and chemicals were of analytical grade.

2.2. Acid soaking optimization

The ground soybean meal was treated with dilute sulfuric acid solution (sample/solution liquid ratio = 1:5) in a stainless steel container immersed in a temperature-controlled water bath maintained at 80 °C for 2 h (Wagner and Guéguen, 1995). The container was equipped with a stirrer to ensure proper mixing of soybean meal with the acid solution. The sulfuric acid concentrations were examined in a range between 0% and 1.2% (w/v). Soaking in deionized water was referred to as a non-acid condition. Following the acid and non-acid treatment, the slurry was filtrated through the eightfold gauze to separate excess sulfuric acid. After filtration, the moisture content of soaked soybean meal was about 70%.

2.3. Steam flash-explosion treatment

About 2 kg of acid soaked and non-acid soaked soybean meal was loaded into a 5-L reactor of the SFE system (Fig. 1). The mechanism of SFE system is different from that of conventional steam explosion machine. In that SFE system adopts a structure in catapult explosion mode that is principally composed of a cylinder and piston. The force of the piston drive system which is composed of a linear actuator and a solenoid valve, comes from compressed air (Yu et al., 2012). The reactor is equipped with a high-pressure autoclave with gas inlet. When the saturated steam was quickly allowed to enter the reactor and steam pressure was maintained for expected time, the steam inlet was shut off and the piston dive device was triggered. The explosion was completed in about millisecond. The samples were carefully recovered, sealed in plastic bags and frozen.

2.4. Description of experimental design

In the acid soaking optimization study, acid soaked and non-acid soaked soybean meal was treated at 1.8 MPa for 10 min. After SFE treatment, the protein extraction yield of soybean meal was examined. When the sulfuric acid concentration was determined, the acid-soaked soybean meals was then treated at 1.4 MPa, 1.6 MPa, 1.8 MPa, 2.0 MPa and 2.2 MPa for 8 min, and the protein extraction yield of SFE-treated soybean meal was examined. In the study of residence time of SFE, the acid-soaked soybean meal was treated at 2.0 MPa for different residence times, and the protein extraction yield soybean meal was examined.

All experimental set points were carried out in triplicate. For every experiment, the materials recovered from receiver were carefully mixed together and constituted a unique batch.

2.5. Protein extraction and soy protein isolate preparation

Pretreated soybean meal slurry samples were dispersed in deionized water in a beaker to maintain a solids-to-water ratio of 1:10 (w/w). The slurry was placed in a 60 °C water bath and stirred for 45 min with pH maintained at 8.5. The samples were then centrifuged at 10,000 g for 20 min at 20 °C. The supernatant was

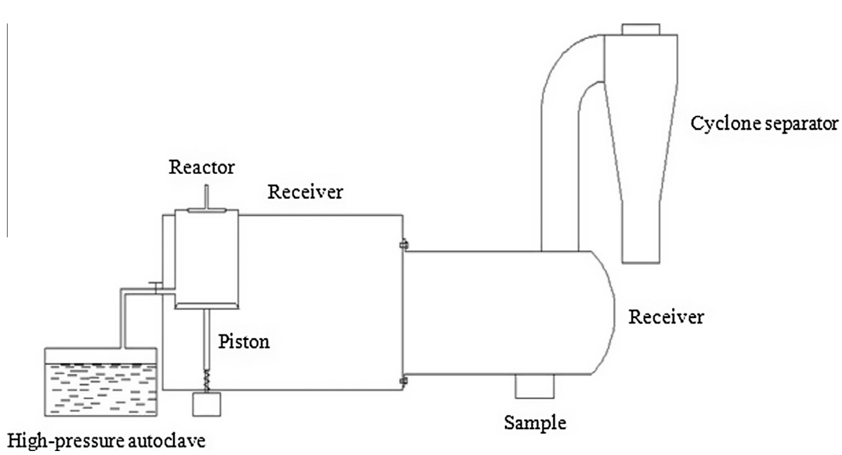

Fig. 1. Steam flash-explosion system.