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Effects of twin-screw extrusion on soluble dietary fibre and physicochemical properties of soybean residue

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ABSTRACT

Extrusion cooking technology was applied for soluble dietary fibre extraction from soybean residue. Response surface methodology (RSM) was used to optimise the effects of extrusion parameters, namely extrusion temperature (90–130 °C), feed moisture (25–35%) and screw speed (160–200 rpm) on the content of soluble dietary fibre. According to the regression coefficients significance of the quadratic polynomial model, the optimum extrusion parameters were as follows: extrusion temperature, 115 °C; feed moisture, 31%; and screw speed, 180 rpm. Under these conditions, the soluble dietary fibre content of soybean residue could reach to 12.65% which increased 10.60% compared with the unextruded soybean residue. In addition, the dietary fibre in extrude soybean residue had higher water retention capacity, oil retention capacity and swelling capacity than those of dietary fibre in unextruded soybean residue.

1. Introduction

The definition of dietary fibre (DF) proposed by the American Association of Cereal Chemists (AACC) defines DF as being made up of edible parts of plants or analogous carbohydrates that are resistant to digestion and absorption in the human small intestine with complete or partial fermentation in the large intestine (AACC Report, 2000). According to the solubility in water, total dietary fibre (TDF) can be categorised into two groups, namely soluble dietary fibre (SDF) and insoluble dietary fibre (IDF) (Vasanthan, Gaosong, Yeung, & Li, 2002). Many studies have shown that DF plays different physiological roles in human health and the SDF appears to be more effective than IDF in many healthy aspects (Esposito et al., 2005; Lou & Chi, 2009). But the most of crude dietary fibre are IDF, while the content of SDF are very low. Therefore, it has special significance to improve the SDF content of crude dietary fibre.

Soybean residue is the main by-product from soymilk and tofu preparation, which is a good dietary fibre resource (Mateos-Aparicio, Mateos-Peinado, & Ruperez, 2010). The content of TDF in soybean residue is about 60%, while the SDF content is only approximate 2–3%. Extrusion cooking is a thermal processing that involves the application of high heat, high pressure, and shear forces to an uncooked mass, such as cereal foods (Kim, Tanhehco, & Ng, 2006). Extrusion technology is a new economical processing methods, it can achieve protein, starch and cellulose polymer transformation directly or indirectly in a short time (Valentina, Paul, Andrew, & Senol, 2010). Extrusion of cereal-based products has advantages over other usual processing methods because of low cost, short time, high productivity, versatility, unique product shapes, and energy savings (Faraj, Vasanthan, & Hoover, 2004; Farouk, Pudil, Janda, & Pokoeny, 2000). In recent years, a number of researchers use barley flour and oat bran to prepare SDF (Vasanthan et al., 2002; Zhang, Bai, & Zhang, 2011). But there has no been relative reports about that using twin-screw extruder to prepare SDF from soybean residue. The results of our previous study (extrusion parameter: extrusion temperature, 160 °C; feed moisture, 20%; and screw speed, 175 rpm) also showed that the extrusion temperature of single screw extruder was too high, which consumed more energy and it is not benefit for industrial production. Therefore, the purpose of the present study was to employ response surface methodology to optimise the effect of different extrusion conditions on the content of SDF in soybean residue, thereby providing a reference for the preparation of high yield of soluble dietary fibre and its industrial production.

2. Materials and methods

2.1. Materials

Soybean residue was supplied by bean products factory of Northeast Agricultural University (Harbin, China). Heat stable α-amylase, Protease and Amyloglucosidase were obtained from Sigma Chemical Company. All the other reagents were of analytical grade.

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2.2. Extrusion experiments

Soybean residue sample (1.5 kg) was extruded with a DS56-III twin-screw co-rotating, self-wiping extruder (Jinan Saixin Machinery Co., Jinan, China). The barrel diameter and length were 65 and 1008 mm, respectively, the screw speed up to 250 rpm. A screw configuration that was a standard design for processing cereals and flour-based products was used. This screw profile was made up of conveying self- wiping elements and the center distance of two screw was 56 mm. The feed moisture of 20%, 25%, 30%, 35% and 40% were selected according to the results of pre-experiments and references. The extrusion temperature was adjusted to 70, 90, 110, 130 and 150 °C, while screw speed of 140, 160, 180, 200 and 220 rpm were employed. The extruded soybean residue was dried in an oven at temperature of 60 °C, ground in a high speed disintegrator (Dade pharmaceuticals company, Wenzhou, China) to obtain a fine power (Particle size: 0.425 mm), then stored at room temperature until analysed.

2.3. Analytical methods

2.3.1. General methods

Total nitrogen content was determined by the Kjeldahl method. A conversion factor of 6.25 was used to calculate protein on the basis of nitrogen. Oil was extracted for 24 h with diethyl ether in a Soxhlet system. Ash was determined by incineration in a furnace at 550 °C and weighed. In all cases the AOAC (2005) methods were followed.

2.3.2. Determination of dietary fibre content

The contents of TDF, SDF and IDF in unextruded and extruded soybean residue were determined according to the AOAC 991.43 enzymatic–gravimetric method (AOAC, 2005). In brief, dried power samples were first gelatinized with heat stable α-amylase (95 °C, 35 min). After gelatinization, the samples were digested with protease and amyloglucosidase to remove protein and starch in the samples. Subsequently, IDF was filtered and washed with 60 °C distilled water. The filtrate and washed water were combined and added with four volumes of 95% ethanol to precipitate the SDF. The residues were weighed after drying at 105 °C in a hot air oven. TDF was calculated as the sum of IDF and SDF.

2.3.3. Water retention capacity (WRC)

Fifteen millilitres of distilled water was added to 250 mg of sample in a 15 mL centrifuge tube. The sample was stirred and left at room temperature for 1 h. After centrifugation at 3000*g* for 20 min, the supernatant was discarded, the residue was weighed and WRC was calculated as g water per g of dry sample (Robertson et al., 2000).

2.3.4. Oil retention capacity (ORC)

The same protocol as above was followed, but using commercial virgin olive instead of water. ORC was expressed as g olive oil retained per g of dry sample (Robertson et al., 2000).

2.3.5. Swelling capacity (SC)

The sample (250 mg) was weighed in a 10 mL measuring cylinder and 5 mL distilled water, containing 0.02% sodium azide added. Then, it was stirred gently to eliminate trapped air bubbles and left on a level surface at room temperature overnight to allow sample to settle. Finally, the volume (mL) occupied by the sample was measured and SC was expressed as mL per g of dry sample (Robertson et al., 2000).

2.4. Experimental design

The effect of three independent variables on the response was studied using a three-level, three-factor factorial Box-Behnken design (BBD) of Response Surface Methodology (RSM) (Ferreira, Duarte, Ribeiro, Queiroz, & Domingues, 2009). The three independent variable sets were feed moisture (%, X_1), extrusion temperature (°C, X_2), screw speed (rpm, X_3), and each variable was set at the three levels. The range and levels of the variables investigated are given in Table 1. A total number of 17 experiments were designed (Table 2). Each experiment was performed in triplicate and the soluble dietary fibre content of soybean residue (%) was taken as the response, *Y*. The design matrix with 17 experimental runs in two blocks with five replicates of the midpoint is shown in Table 2. Regression analysis was performed for the experiment data and fitted to the empirical second order polynomial model, as shown in the following equation:

$$Y = \beta_0 + \sum_{i=1}^{3}\beta_i X_i + \sum_{i=1}^{3}\beta_{ii} X_i^2 + \sum_{i=1}^{2}\sum_{j=i+1}^{3}\beta_{ij} X_i X_j \quad (1)$$

where *Y* is the response variable, β_0 β_i β_{ii} and β_{ij} are the regression coefficients of variables for constant, linear, quadratic, and interaction regression terms, respectively; X_i and X_j are the coded values of the independent variables. The fitted polynomial equation is expressed as surface and contour plots in order to visualise the relationship between the response and experimental levels of each factor and to deduce the optimum conditions (Triveni, Shamala, & Rastogi, 2001).

2.5. Statistical analysis

All experiments were carried out in triplicates. Analysis of variance of the results was performed using the Design-Expert 7.1 software (Statease Inc., Minneapolis, USA). The significances of all terms in the polynomial were judged statistically by computing the *F*-value at a probability (p) of 0.01 and 0.05. All calculations and graphics were performed using the Origin7.0 software.

Table 1
The range of independent variables and their corresponding levels.

Independent variables	Symbol	Coded factor level		
	Coded	−1	0	1
Feed moisture (%)	X_1	25	30	35
Extrusion temperature (°C)	X_2	90	110	130
Screw speed (rpm)	X_3	160	180	200

Table 2
Design and results of experiment.

Run	Feed moisture X_1	Extrusion temperature X_2	Screw speed X_3	The content of SDF (%)
1	1	0	−1	11.13
2	−1	1	0	10.98
3	0	0	0	12.56
4	0	1	1	11.46
5	0	0	0	12.38
6	0	0	0	12.43
7	0	0	0	12.55
8	−1	0	−1	10.59
9	0	1	−1	11.15
10	0	−1	1	10.55
11	0	−1	−1	9.25
12	−1	−1	0	9.58
13	1	0	1	11.59
14	1	−1	0	10.68
15	1	1	0	11.73
16	−1	0	1	10.81
17	0	0	0	12.68