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Modeling the effects of microfluidization conditions on properties of corn bran

Fuli He, Tao Wang, Si Zhu, Guibing Chen*

Center for Excellence in Post-Harvest Technologies, North Carolina A&T State University, The North Carolina Research Campus, 500 Laureate Way, Kannapolis, NC, 28081, USA

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ABSTRACT

Corn bran was microfluidized through a 200-μm channel in the pressure range of 124.1–158.7 MPa for 1–5 passes following the central composite experimental design. Physicochemical properties and antioxidant properties of microfluidized bran samples were measured and fitted to the second order polynomial model. The response surface equations obtained showed that all the properties examined had a positive linear relationship with pressure and a negative quadratic relationship with number of passes except for ABTS radical scavenging activity which was quadratically related to both processing parameters. The number of passes generally had a more pronounced effect on the examined properties compared with pressure. Within the experimental range, the maximum values of swelling capacity, water-holding capacity, and oil-holding capacity were respectively 10.62 ml/g d.w. (at 158.7 MPa), 5.49 g water/g d.w. (at 158.7 MPa), and 4.61 g oil/g d.w. (at 124.1 MPa); the maximum values of surface reactive phenolic content, DPPH and ABTS radical scavenging activities were 148.80 mg/FAE g d.w. (at 158.7 MPa), 50.02 μmol TE/g d.w. (at 158.7 MPa), and 47.90 μmol TE/g d.w. (at 145.9 MPa), respectively. All maximum values of the properties occurred at 5 passes.

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1. Introduction

Corn bran is an ideal source of dietary fiber and phenolic antioxidants for human diets. Numerous studies support that sufficient intake of dietary fiber plays a protective role against obesity (Slavin, 2005) and many other chronic diseases (Anderson et al., 2009). Corn bran contains the highest amount of ferulic acid, a potent phenolic antioxidant, compared to other tested grains (Vitaglione et al., 2008; Zhao and Moghadasian, 2008). Phenolic antioxidants can modulate cellular oxidative status and prevent biologically important molecules such as DNA, proteins, and membrane lipids from oxidative damage (Yu et al., 2002). In addition, unlike other cereal brans, high-fiber diets containing corn bran are less likely to cause discomfort due to its lower level of intestinal gas excretion (Marthinsen and Fleming, 1982).

It has been shown that suitable processing technologies could effectively improve physiochemical and health-related properties including hydration properties, oil holding capacity, antioxidant activity, etc., of various types of dietary fiber and cereal bran (Chau et al., 2006; Chou et al., 2008; Wang et al., 2013, 2014a). Such enhancement is of great interest for a few reasons. First, the same health benefits may be achieved by consuming less amount of dietary fiber. This is favorable because consuming large quantities of dietary fiber increases gas production and also retards intestinal gas transit (Gonlachanvit et al., 2004). Second, it facilitates development of foods fortified with fiber ingredients because adding a high level of dietary fiber to foods adversely affects color, texture, flavor and taste of the supplemented foods (Onwulata, 2008; Robin et al., 2012). Finally, most ferulic acids in cereal brans are bound to the fiber matrix, leading to poor bioaccessibility (Saulnier et al., 1995). Suitable processing technologies can reduce particle size and/or loosen the microstructure of cereal bran and thus increase bioaccessiblity of bound phenolic compounds (Wang et al., 2014b).

Microfluidization is a process that applies a high pressure to

Abbreviations: ABTS, 2,2′-azino-bis(3-ethylbenzothiazoline-6-sulphonic acid); AP, adequate precision; CS, calculated specific surface area; CV, coefficient of variation; DPPH, 1,1-diphenyl-2-picrylhydrazyl radical; FAE, ferulic acid equivalents; MV, mean volume diameter; OHC, oil-holding capacity; PSD, particle size distribution; SC, swelling capacity; SRPC, surface reactive phenolic contents; SS, sum of squares; TE, Trolox equivalents; TEAC, Trolox equivalent antioxidant capacity; TROLEX, 6-hydroxy-2,5,7,8-tetramehylchroman-2-carboxylic acid; WHC, water-holding capacity.

* Corresponding author.
E-mail address: gchen@ncat.edu (G. Chen).

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drive a liquid stream carrying solid particles (suspensions) or liquid droplets (emulsions) through a microchannel in the interaction chamber of a microfluidizer. During the process, the carried particles or droplets are subjected to extremely high shear stress, impact force, and instantaneous pressure release, resulting in particle size reduction and loosened microstructure of solid particles. Microfluidization process has been used in pharmaceutical industry for preparing emulsions and encapsulation and in food industry for homogenization and deagglormeration (An et al., 2012; Guraya and James, 2002; Han et al., 2014). Recently, we demonstrated that this process dramatically improved physiochemical properties and antioxidant activity of corn bran primarily because it reduced bran particle size and loosened microstructure of bran matrix, making more reactive groups accessible to reagents present in an aqueous medium and more internal pore spaces in bran particles available for holding liquids such as water and oil (Wang et al., 2013, 2014a). Since processing pressure and number of passes may contribute differently to particle size reduction and porosity increase, they may affect properties of corn bran in different ways during a microfluidization process. Such information is important in optimizing a processing condition to achieve desired properties of corn bran with minimum operating costs.

The objective of this study was to correlate physiochemical and antioxidant properties of corn bran with processing pressure and number of passes during microfluidization processes, and to determine processing conditions for the maximum values of these properties within the range of experimental conditions.

2. Materials and methods

2.1. Materials and chemicals

Fine wet milled corn bran samples comprising 3.5% fat, 82.4% total dietary fiber, 9.3% water, and 4.8% others were purchased from Cargill Dry Corn Ingredients, Inc. (Paris, IL, USA). All the chemicals and reagents were of analytical grade and purchased from Sigma-Aldrich (St. Louis, MO. USA).

2.2. Preparation of microfluidized corn bran

An M-110P Microfluidizer Processor (Microfluidics, Newton, MA) was used for the process. Raw corn bran was repeatedly ground using a Waring laboratory blender (model MX-LB10S) until passing through a US standard No. 35 sieve with a nominal opening of 500 μm (Fisher Scientific Co. TX, USA). Ground corn bran was dispersed in distilled water at a ratio of corn bran: water 1:9 (wt/wt). The suspension was then processed through a 200 μm interaction chamber, at room temperature, 124.1–158.7 MPa pressure, and for 1–5 passes according to the experiment design. The processed bran samples were collected by filtration and freeze-dried using Labconco FreeZone Freeze Dry System (Kansas City, MO, USA). Dry samples were sealed in air-tight glass containers and stored at −30 °C for analysis. All experiments were performed in triplicate. About 150 g of raw corn bran were processed per run.

2.3. Experimental design

In order to investigate the effects of microfluidization conditions on properties of corn bran, a total of 13 experimental runs with different combination of processing pressure (X_1, 124.1–158.7 MPa) and number of passes (X_2, 1–5) were conducted based on the central composite design (CCD) (Table 1). The predicted responses of properties examined were calculated using a second-order polynomial model shown by Eq. (1):

$$Y = b_0 + \sum_{i=1}^{2} b_i X_i + \sum_{i=1}^{2} b_{ii} X_i^2 + \sum_{i=1}^{2} \sum_{j=i+1}^{2} b_{ij} X_i X_j \quad (1)$$

where Y is the response variable, b_0, b_i, b_{ii}, and b_{ij} are the constant, linear, quadratic, and cross-product regression coefficients, respectively, and X_i and X_j are the coded independent variables of X_1 and X_2, respectively.

Software Design Expert 9.0.3 (Stat Ease, USA) was used for analysis of variance (ANOVA), regression analysis of the data, and plotting of response surface figures.

2.4. Determination of particle size distribution

Particle size distribution (PSD) was analyzed using a Bluewave Laser Particle Analyzer (Microtrac, Montgomeryville, PA, USA). The values of mean volume diameter (MV) and calculated specific surface area (CS) were recorded.

2.5. Measurement of bulk density

Five hundred mg of corn bran sample was weighed and carefully transferred into a calibrated 10 ml graduated cylinder. Then the cylinder was gently tapped on a bench-top until no further decrease in sample volume. The bulk density (g/ml) was calculated as weight (g) per volume of sample (ml).

2.6. Swelling capacity

Swelling capacity (SC) was determined using a reported method (Robertson et al., 2000). Weighed dry bran sample (0.500 ± 0.001 g) was added into a 20 ml graduated cylinder. 10 ml distilled water was poured into the cylinder and gently mixed well with the bran sample. The cylinder was then covered with parafilm and let to stand overnight at room temperature. The volume occupied by the settled sample was recorded. The SC was expressed as volume of swollen sample per gram dry sample weight (ml/g d.w.).

2.7. Water-holding capacity

Water-holding capacity (WHC) was determined according to a reported method (Robertson et al., 2000) with some modifications. In brief, corn bran sample (0.500 ± 0.001 g) was weighed in a 50 ml centrifuge tube; 20 ml of distilled water was added and allowed to hydrate at room temperature for 24 h. Then samples were centrifuged (3000*g*) for 10 min and the supernatant was carefully removed. WHC was expressed as the amount of water retained per gram dry sample weight (g water/g d.w.).

2.8. Oil-holding capacity

Oil-holding capacity (OHC) was determined by following the procedure for WHC test described above with water being replaced by corn oil and expressed as: g oil/g d.w.

2.9. Surface reactive phenolic contents

Surface reactive phenolic content (SRPC) of ground raw and microfluidized corn bran was assessed using a direct procedure described in our previous study (Wang et al., 2014a). Briefly, Folin-Ciocalteu reagent (2.5 ml, 10% v/v) was added to 2.5 mg of corn bran sample, and sodium carbonate (2 ml, 7.5% w/v) was added after 5min. The mixture was incubated for 2 h at room temperature, being vortexed several times during the incubation, and then

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