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Optimization of air jet impingement drying of okara using response surface methodology

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ABSTRACT

Okara is a byproduct from the process of soybean foods, and is rich in proteins, fatty acids and dietary fibers. Drying of wet okara is essential for long-term storage and its value-added applications. This study applied response surface methodology and synthetic evaluation method to optimize the drying process of okara in an air jet impingement drier (AJID). Air temperature (50–70 °C), air velocity (1.3–2.3 m/s), and sample loading density (3–4 kg/m^2) were considered as treatment factors in the optimization, while drying rate, color, trypsin inhibitor activity, soy isoflavone content and antioxidant activity were evaluated as responding quality parameters. All treatment variables showed significant effects on the drying rate and soy isoflavone content ($P < 0.05$). Higher temperature, higher air velocity and lower loading density contributed to higher drying rate. Temperature and air velocity showed quadratic and interactive effect on the antioxidant activity of okara. The optimum conditions for AJID of okara were identified as 70 °C, 2.3 m/s air velocity, and 3 kg/m^2 loading density. This process control study provided baseline data for developing effective drying of okara using AJID.

1. Introduction

Okara is a byproduct from the process of soybean foods, such as soy milk and Tofu (O'Toole, 1999). Okara is rich in proteins, lipids and dietary fibers, and could be used as ingredient for animal feed and human food (Surel & Couplet, 2005). However, fresh okara deteriorates rapidly owing to the high moisture (75–80%) and protein contents (29% on the dry basis) (Taruna & Jindal, 2002; Wachiraphansakul & Devahastin, 2005). Drying okara to low moisture content while retaining its functional quality is essential for long-term storage and value-added applications.

Several drying technologies have been investigated to process okara. For examples, flash air drying decreased water content of okara to 6% in less than 2 min, but this method could only process on raw material of which the water content as high as 74%, less than that of the fresh okara (Grizotto & Aguirre, 2011). Therefor pre-drying of the fresh okara by a tray dryer was required. Combined convection-sorption method using a jet spouted bed of sorbent particles had shown good quality of dried okara in respect to oxidation level, rehydration ability and protein solubility (Wachiraphansakul & Devahastin, 2007). However, since the silica gel was used as a sorbent material, the product might not be applicable to human food. While the electro hydrodynamic (EHD) technique could promote the drying rate greatly comparing with oven drying (105 °C) without high electric field (Li, Li, Sun, & Tatsumi, 2006), this method is still in its development stage at lab scale. The continuous entrained bed dryer (Itaya, Kobayashi, & Nakamiya, 2010) and the impinging stream dryer have displayed high efficiency in drying okara (Choicharoen, Devahastin, & Soponronnarit, 2011). Unfortunately, the hot air temperature used in the continuous entrained bed dryer and the super-heated steam in the impinging dryer were as high as 190 °C, thus deteriorating the quality of the dried okara. Therefore, development of an efficient and economically feasible technology to dry okara with

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retained quality is important and urgent to the soybean processing industry. Air jet impingement drying (AJID) uses high speed air to impinge the surface of the drying material for increasing the heat transfer rate (Anderson & Singh, 2006). Xiao, Pang, et al. (2010) and Xiao, Gao, Lin, Yang (2010) investigated the drying kinetics of Monukka seedless grapes in AJID and evaluated the quality of dried grapes, and found that higher air temperature from 50 to 65 °C contributes to higher drying rate, firmer texture, higher moisture effective diffusivity, but lower retention of vitamin C. Supmoon and Noomhorm (2013) compared the effects of combined hot air impingement and infrared dryer (IMIRD) on potato chips, and observed that IMIRD yielded a higher drying rate, in which the resulted potato chips had less shrinkage, softer texture, and less color deterioration. However, no study has reported the use of AJID to dry okara yet. By considering the high efficiency and feasibility, therefore, this study was developed to understand the impact of AJID on okara quality and to identify the optimal drying conditions that can be adapted by soybean processing industry using response surface methodology.

Response surface methodology (RSM) has been frequently used to develop, improve, and optimize processing conditions in various processes (Myers, Montgomery, & Anderson-Cook, 2009). It could reduce the number of experimental runs to evaluate multiple variables and their interactions on the responses. Hence, RSM was employed in this study to develop the optimal drying conditions of AJID for drying okara. Synthetic evaluation method was usually applied to optimize drying process (Zhang, Zhang, Lü, & Wang, 2011). It could turn multi-objective optimization problem into single-objective optimization problem. The variables with different dimensions could be converted into dimensionless data and analyzed together. The weighing factors show the importance of each variables.

In this study, temperature, air velocity, and loading density were considered as the main treatment factors for drying okara using AJID. Drying rate, color, trypsin inhibitor activity, soy isoflavone content, and antioxidant activity of dried okara were evaluated as the responding quality parameters to determine the optimum drying conditions. Results generated from this study would provide baseline data for the use of AJID as an alternative technique for drying okara.

2. Materials and methods

2.1. Materials

Fresh okara with an initial moisture content of 82–85% (w.b.) was obtained from the soybean milk powder production line in Wilmar (Shanghai) Biotechnology Research & Development Center Co. Ltd. The fresh okara was sealed in the plastic bags (HDPE), stored at a −80 °C freezer (HFU 686 Basic, Thermo, German), and thawed at a 5 °C refrigerator before usage.

Genistein and Nα-benzoyl-DL-arginine-4-nitroanilide hydrochloride (L-BAPA) were purchased from Sinopharm Chemical Reagent Co., Ltd (China). Trypsin from bovine pancreas, and 1,1-Diphenyl-2-picryl-hydrazyl (DPPH) were obtained from Sigma–Aldrich (USA). Ascorbic acid was purchased from Shanghai Lingfeng Chemical Reagent Co. Ltd. (China).

2.2. Drying process

The air jet impingement drying (AJID) applied in this study was from Qiang'an Catering Equipment Co., Ltd., China (Model H1820). Okara was evenly distributed on a mesh tray (172 × 156 mm) with the loading density of 3, 4 or 5 kg/m^2, which was put on the conveyor belt in the drying chamber. Hot air was blown from both the top and the bottom of the chamber with the same velocity at 1.3, 1.8 or 2.3 m/s. Air temperature was set up at 50, 60 or 70 °C. The levels of loading density were selected according to our preliminary study, in which when the loading density was higher than 5 kg/m^2, the okara cake was too thick to dry thoroughly. The air velocity was selected based on the range of the dryer (1.0–2.3 m/s). Since soy protein may denature when temperature is higher than 70 °C (Wachiraphansakul & Devahastin, 2007), drying temperature was set up below 70 °C to retain the quality of okara. After drying, the okara cake from each batch was ground and mixed with samples from other batches for further analysis.

During the drying process, the sample tray was taken out to weigh every 30 min for determining the change of moisture content. When it was close to 8%, the sample tray was weighed every 5 min until it was just below 8% to terminate the drying process.

2.3. Moisture content and drying rate (DR)

Moisture content (d.b.) of the dried okara was determined in triplicate by drying 2.0 g of okara to a constant mass at 105 °C oven (GZX-DH, Shanghai Yuejin Medical Instrument, China) according to the method GB 5009.3-2010. Drying rate was defined as the average value of moisture changes during the drying process, calculated using Eq. (1), and expressed as g water/100 g dry solids per min.

$$\text{Drying rate} = \frac{(MC_0 - MC_1)*100}{Drying\ time} \quad (1)$$

where MC_0 and MC_1 were the moisture content of the fresh sample and the dehydrated sample on dry basis, respectively.

2.4. Color

The chromaticity index (L*, a* and b* values) of dried okara were measured in triplicate using a colorimeter (LabScanXE, Hunter Lab, USA). A 5 g of sample was used for each measurement.

2.5. Trysin inhibitor activity (TIA)

TIA of dried okara was determined according to GBT 21498-2008 standard. Briefly, 1.0 g of the sample was suspended in 50 mL of NaOH solution (0.01 mol/L), and stored at 4 °C for 18 h. The mixture was diluted to 100 mL with deionized water. After precipitating for 15 min, the supernatant was collected.

Four reaction systems including blank standard (bs), standard (s), blank reactant (br), and reactant (r) were prepared with specific reagents and operating steps. Blank standard consisted of 5 mL of L-BAPAS, 3 mL of water, 1 mL of acetic acid (5.3 mol/L), and 1 mL of trypsin solution. Standard composed of 5 mL of L-BAPAS, 3 mL of water, 1 mL of trypsin solution, and 1 mL of 5.3 mol/L acetic acid. Blank reactant was 5 mL of L-BAPAS, 1 mL of sample solution, 2 mL of water, 1 mL of 5.3 mol/L acetic acid, and 1 mL of trypsin solution. Reactant was 5 mL of L-BAPAS, 1 mL of sample solution, 2 mL of water, 1 mL of trypsin solution, and 1 mL of acetic acid (5.3 mol/L). All reaction systems were placed in a water bath at 37 °C for 10 min before and after adding trypsin solution, and centrifuged (Z-326K, Hermle Labortechnik GmbH, Germany) for 10 min (4000 rpm/min). The supernatant was used for absorbance measuring using UV spectrophotometer (UV-1800, Shimadzu, Japan).

Nα -benzoyl-DL-arginine-4-nitroanilide hydrochloride (L-BAPA) (60 mg/100 mL) was used as a substrate. L-BAPAS: 60 mg of L-BAPA was dissolved in 100 mL of Tris-$CaCl_2$ solution (6.05 g of Tris and 0.735 g of $CaCl_2$ in 1000 mL of water, pH 8.2). The trypsin solution was prepared by dissolving 13.5 mg of trypsin in 1000 mL of