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Tailoring physicochemical and sensorial properties of defatted soybean flour using jet-milling technology

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ABSTRACT

The effects of jet-milling on the physicochemical and sensorial properties of defatted soybean flour (DSF) were investigated. Superfine DSF powder (DSF-JM; D_{50} = 4.3 ± 0.1 μm) was prepared from DSF powder (DSF-150; D_{50} = 257.0 ± 1.7 μm) via conventional sifting followed by jet-milling. The jet-milled DSF showed significant increases in hydration properties, with increases in the water-holding capacity, water-solubility index, and swelling capacity of 24%, 39%, and 32%, respectively. Soluble dietary fibre and fat-binding capacity of DSF-JM also increased significantly ($p < 0.05$). A quantitative descriptive analysis by trained panelists indicated that the sensorial properties of DSF were also modified by jet milling. The DSF-JM showed significant reductions in bitterness and roughness, but sweetness increased, and the colour of DSF-JM changed to a brighter achromatic colour. These results indicate that superfine DSF could be an ingredient used to modify physical and sensorial properties of food.

1. Introduction

A large quantity of defatted soybean flour (DSF) is produced as a by-product of soybean oil. DSF contains high levels of dietary fibre (2.6–17.5%), as well as proteins, carbohydrates, and fat (Berk, 1992). Phytoestrogens, saponins, phytosterols, isoflavones, antioxidants, and essential amino acids are also included in DSF (Dia, Wang, Oh, Lumen, & de Mejia, 2009; Mendel & Brandon, 2001; Wu & Muir, 2010). DSF is commercially available in the global food market and is in food products, such as textured vegetable meat, breakfast cereal, and snacks (Adelakun, Duodu, Buys, & Olanipekun, 2013). Other examples of DSF as a raw, substitute, or fortification material for food products include wheat bread (Dhingra & Jood, 2001; Shogren, Mohamed, & Carriere, 2003), Egyptian bread (Abdel-Rahman & Youssef, 1978), cereal-based food (Roopchand et al., 2012), and extruded products (Lobato, Anibal, Lazaretti, & Grossmann, 2011).

However, the bitter taste and rough mouthfeel of DSF restrict its use as a food ingredient. A bitter or beany taste occurs due to lipoxygenase-catalysed oxidation of soybean oil to volatile compounds, and the increased quantity of DSF results in a bitter taste in the final product (Shogren et al., 2003). Panelists' acceptance of the flavour and taste properties of DSF-fortified wheat bread decreases with an increase in DSF content (Mashayekh, Mahmoodi, & Entezari, 2008). Roughness is related to the particle size of the raw material, and the overall acceptance for a fibre-enriched layer cake decreased with an increase in fibre particle size (Gómez, Moraleja, Oliete, Ruiz, & Caballero, 2010). Particle sizes of the raw materials also affect physicochemical properties as well as the extractability of the food material. Hydration properties and protein solubility increased in a superfine powder of *Agrocybe Chaxingu Huang* and silver carp bone (Wu, Zhang, Wang, Mothibe, & Chen, 2012; Zhang, Zhang, & Shrestha, 2005). Protein recovery from soy protein isolates increased to 52% after decreasing the average particle diameter (Russin, Arcand, & Boye, 2007). The maximum protein recovery of 97% was achieved when fine soya bean particles <75 μm were used (Vishwanathan, Singh, & Subramanian, 2011). Particle size also influences the extraction of phytochemicals from wheat bran (Brewer, Kubola, Siriamornpun, Herald, & Shi, 2014).

Micro- and nanotechnology show great potential in biomedical and food manufacturing (Sanguansri, 2006; Sigh, Kulkarni, & Dash, 2013). Reducing the particle sizes of various materials to the micro or nano range changes the structure and adds new beneficial characteristics to the bulk materials (Zhu, Huang, Peng, Qian, & Zhou, 2010). A smaller size means a larger surface area, resulting in improved water absorption, high solubility, flavour release, and a soft mouthfeel. Jet milling is a prospective method to prepare

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micro- or nano-sized particles (Nykamp, Carstensen, & Muller, 2002), and this method employs a top-down approach to produce an ultrafine powder. The final particle size produced by this method is strongly dependent on the material being processed but can easily be processed to 1000 nm (Sanguansri, 2006). A fluidized jet mill is a highly efficient piece of equipment that achieves the maximum micronization of alumina particles (Wang & Peng, 2011), silica (Palaniandy, Azizli, Hussin, & Hashim, 2008), talc (Alfano, Saba, & Suracco, 1996), ethenzamide (Fukunaka, Golman, & Shinohara, 2006), and fenofibrate with minimum power consumption (Hiendrawan, Veriansyah, & Tjandrawinata, 2014). However, using jet milling to prepare food material is rarely reported. The objective of this study was to apply jet-milling technology to prepare a superfine DSF powder and observe its effects on the physicochemical and sensory characteristics of food.

2. Materials and methods

2.1. Materials

Food-grade DSF was obtained from Sam Chang Industry (Anseong, Korea). Raw DSF was passed through a two-step sieve (150- and 63-μm testing sieves, Nonaka Rikaki, Tokyo, Japan) to obtain the appropriate particle size, and powder that did not pass through the 150-μm sieve was collected as DSF-150. Samples that passed through the 150- and 63-μm sieves were collected as DSF-63, which was processed into a superfine powder using a fluidized bed jet mill (CGS 10, Netzsch, Selb, Germany). The jet-milling processing conditions were 7 bars of milling pressure and 12,000 rpm for the classifier, and the jet-milled DSF was collected as DSF-JM.

2.2. Methods

2.2.1. Particle-size distribution

The particle-size distributions of the DSF samples were determined with a laser diffraction particle-size analyzer (Mastersizer 3000, Malvern Instruments Ltd., Malvern, Worcestershire, UK). The amount of sample poured into the inlet chamber and DSF particle size were measured automatically by laser diffraction.

2.2.2. Scanning electron microscopic analysis

Microstructure of the DSF samples was examined by scanning electron microscopy (SEM; S-3400N, Hitachi, Tokyo, Japan). The samples were affixed to carbon tape and an aluminium stub and coated with platinum–lead (Pt–Pb) under a vacuum before observations. The DSF microstructural images were observed at 5 kV with magnifications of 300× and 1000×.

2.2.3. Determining bulk density, tap density, and flowability

Bulk density was measured by pouring the DSF samples into a 100-ml top-fitted graduated cylinder. The weight of the mass cylinder filled with 100 ml of powder was measured. Bulk density was defined as powder weight (g) divided by powder volume (100 ml). A sample for the tap density measurement was added to a 100-ml top-fitted graduated cylinder and tapped 100 times to remove gaps among particles. More powder was added to the cylinder, and it was tapped again until a stable condition was reached. Tap density was calculated as the weight of the tapped powder (g) divided by the powder volume (100 ml). Flowability of the DSF samples was calculated based on the Carr Index, which is shown as Eq. (1) (Shah, Tawakkul, & Khan, 2008). Carr Index values of 0–15% indicate that the powder has good flowability, 15–25% means it has medium flowability, 25–30% shows poor flowability, and > 30% indicates that the powder has very poor flowability.

$$\text{Carr Index } (\%) = \frac{\text{Tap density} - \text{Bulk density}}{\text{Tap density}} \times 100 \quad (1)$$

2.2.4. Determining soluble dietary fibre, water-holding capacity, water-solubility index, swelling capacity, and fat-binding capacity

Soluble dietary fibre was determined by a method taken from the American Association of Cereal Chemists, AACC Method 32-07.01 (AACC, 1983).

The water-holding capacity (WHC) was measured using a method by Cheickna (2011) with some modifications. A DSF sample (1 g) was poured into a 50-ml graduated Falcon cylinder. Then, 30 ml of distillated water containing 0.02% sodium azide was added and shaken until a homogenous dispersion was observed. The dispersion was left to stand at room temperature for 18 h. The free water was removed by passing the dispersion through pre-weighed filter paper (No. 1, Whatman, Little Chalfont, Buckinghamshire, UK) on sintered glass under an applied vacuum for 10 s. The hydrated residue weight (H1, g) was recorded, and the residue was dried at 110 °C for 24 h in a drying oven to obtain the dry weight (H2, g). WHC was calculated as follows:

$$\text{WHC } (\text{g/g}) = \frac{\text{H1} - \text{H2}}{\text{H2}} \quad (2)$$

The water-solubility index (WSI) was determined using the method of Zhang et al. (2012). One gram of sample (W1) was dispersed in 50 ml of distilled water in a centrifuge tube at ambient temperature. Then, the dispersion was incubated in a water bath at 80 °C for 30 min, followed by centrifugation at 6000 rpm for 10 min. The supernatant was carefully collected on a pre-weighed aluminum dish (W2) and drained at 110 °C for 24 h. The dry residue was weighed (W3). The WSI was calculated as follows:

$$\text{WSI } (\%) = \frac{\text{W3} - \text{W2}}{\text{W1}} \times 100 \quad (3)$$

The swelling capacity was measured using a method by Robertson et al. (2000). A DSF sample (1 g) was hydrated in 10 ml distillated water containing 0.02% sodium azide as a bacteriostat in a graduated 15-ml Falcon tube. The sample was shaken until a homogeneous dispersion formed. Bed volume was recorded after 18 h. The swelling capacity (ml/g) was expressed as the volume occupied by the sample per the original sample dry weight.

The fat-binding capacity (FBC) was determined using a method by Lin, Humbert, and Sosulski (1974). A sample (5 g) was added to 20 ml corn oil in a 50-ml centrifuge tube, which was shaken for 30 s every 5 min. The tube was centrifuged after 30 min at 1600×*g* for 25 min. Then, the free oil was decanted, and the remaining residue was weighed. FBC was expressed as

$$\text{FBC } (\text{g/g}) = \frac{\text{Precipitation weight (g)} - \text{Dry weight (g)}}{\text{Dry weight (g)}} \quad (4)$$

2.2.5. Colour measurements

The colours of the different DSF samples were measured as CIE L^* (lightness), a^* (±, redness/greenness), and b^* (±, yellowness/blueness) values using a colorimeter (UltraScan Pro, HunterLab, Reston, VA, USA), which was calibrated with a standard white surface calibration plate ($L^* = 97.49$, $a^* = -0.13$, $b^* = 0.04$).

2.2.6. Sensorial properties

The sensory properties of the DSF samples were evaluated by quantitative descriptive analysis (QDA) (Meilgaard, Civille, & Carr, 1999; Ng et al., 2012) and modified to use specific products available in local markets. Four sensory property parameters were analysed, such as bitterness, sweetness, roughness, and particle size. Eight trained panelists evaluated the samples in triplicate using