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Effects of superfine grinding on properties of sugar beet pulp powders

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ABSTRACT

The effects of superfine grinding on the properties of sugar beet pulp powders were investigated in contrast to conventional grinding method. The dried sugar beet pulps were prepared to obtain four powders. The superfine grinding produced a smaller particle size powder with the median particle diameter of 24.93 μm. As particle size decreased, the bulk density (from 0.453 to 0.620 × 10^3 kg/m^3), tap density (0.487–0.658 × 10^3 kg/m^3), the angle of repose (33.59–57.97°) and angle of slide (30.92–60.66°) increased. The water binding capacity was affected by particle size and grinding methods. Superfine grinding technology did not improve the oil binding capacity of sugar beet pulp powders. Two endothermic peaks were observed in the differential scanning calorimetry curves. Superfine grinding decreased the melting temperature and the crystallinity index values. In addition, the X-ray diffraction patterns of sugar beet pulp powders produced by superfine grinding technology behaved different peak position but the same peak intensity.

1. Introduction

Sugar beet (*Beta vulgaris*) pulp (SBP), a fibrous by-product of sugar refining industry, is mainly employed for feed formulation. Nearly 9 million tons of SBP were produced in China in 2014 according to the FAO statistics. Drying SBP requires high energy costs and presents an environment problem. The low value and abundant production of SBP requires to develop more commercial uses (Ma et al., 2013). At present, some attempts have been made to use SBP as a bio-sorbent for the removal of heavy metal ions, source of pectin, biofuels and dietary fiber (Bertin, Rouau, & Thibault, 1988; Chen, Fu, & Luo, 2015).

Superfine grinding is an emerging technology that is a useful tool for making superfine powder with great surface properties. Superfine powder exhibits small solid particles and some different characteristics compared with crude particles (Zhang et al., 2014). Recently, superfine grinding technology has been applied in biotechnology and food material which draws attention on the extraction of functional components on account of saving time and energy. A number of investigations have been undertaken on the effects of superfine grinding technology on the properties of powders. Superfine grinding produced narrow and uniform particle distribution in ginger powder. Small sized powder exhibited great surface properties (Zhao, Yang, Gai, & Yang, 2009). Hu, Chen, and Ni (2012) prepared six green tea powders which possessed better food processing properties, for instance, the increased contents of water-soluble carbohydrates and antioxidation of green tea powders. Meanwhile, superfine grinding technology had an impact on the structure and physical properties of protein and dietary fiber (Sun et al., 2015; Zhu, Huang, Peng, Qian, & Zhou, 2010).

SBP contains 75–80% polysaccharides, consisting of 22–24% cellulose microfibrils, 26–32% hemicelluloses and 25% pectin (Michel, Thibault, Barry J, & DeBaynast, 1988; Vučurović & Razmovski, 2012). Due to high content of pectin, SBP is mainly used for extraction of beet pectin which exhibits superior emulsifying properties (Ma et al., 2013). SBP pectin is used as an emulsifier rather than as a gelling agent owing to the presence of higher amount of protein and proportion of acetyl groups (Funami et al., 2007). Moreover, highly dietary fiber content of SBP makes it an ideal candidate as a complement for health food (Guillon & Champ, 2000). In the previous studies, conventional grinding methods are generally used in the utilization and research of SBP. The main process generally includes milling and sieving without specific size parameters (Lv, Wang, Wang, Li, & Adhikari, 2013; Sun & Hughes,

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1998; Yapo, Robert, Etienne, Wathelet, & Paquot, 2007). However, up to now, there has been no research on the effects of superfine grinding technique on properties of dried SBP powders.

The objective of our study is to investigate the effects of superfine grinding technology on properties of sugar beet pulp compared with conventional grinding method and to obtain four powders in different particle sizes. Then, their particle sizes, color, bulk and tap density, angle of repose and slide, water and oil binding capacity were determined. The differential scanning calorimetry and X-ray diffraction analysis were also studied in order to get a better understanding of superfine grinding behavior of SBP powder.

2. Materials and methods

2.1. Materials

Sugar beet pulp (SBP) was provided by COFCO Tunhe Co., Ltd. (Xinjiang, China), with moisture content of 33.3 g/kg. Fibrex®575, a commercial sugar beet fiber, was purchased from Nordic Sugar A/S, Copenhagen K, Denmark.

2.2. Preparation of beet pulp powders

Superfine grinding sample of SBP was micronized by using multidimensional swing high-energy nano-impact-milling (CJM-SY-B Qinhuangdao Taiji Ring Nano-Products Co., Ltd., Hebei, China). The coarsely crushed SBP was mixed with ZrO_2 balls (6 and 10 mm in diameter) in a volume ratio of 2:1 for 5 h. The milling jar was covered by a circulating cooling ethylene glycol system, which could control the temperature during milling process below 15 °C. The superfine grinding sample of SBP was designated SG.

Conventionally ground samples of SBP were ground in a high speed multi-function miller (Bingdu Electrical Appliances Co., Ltd., Shanghai, China) and passed through screens with mesh size of 0.45 mm (40-mesh), 0.30 mm (60-mesh) and 0.18 mm (80-mesh). Particle size of samples between 40-mesh and 60 mesh, 60-mesh and 80-mesh, less than 80-mesh were named M40, M60, M80. The powders obtained were packed in the air-tight bag for further analysis. The commercial sample in this study was determined 575.

2.3. Determination of particle size distribution

Particle size distribution of SBP powders produced by different grinding methods was measured by Mastersizer 3000 laser diffraction particle size analyzer (Malvern instrument Ltd., Worcestershire, UK). Particle size distributions were characterized by $D_{0.1}$, $D_{0.5}$ and $D_{0.9}$ values. $D_{0.1}$, $D_{0.5}$ and $D_{0.9}$ are the equivalent volume diameters at 10%, 50% and 90% cumulative volume, respectively. The width of particle size was by span according to the method by Zhang et al. (2012). Span was determined by the equation below:

$$Span = (D_{0.9} - D_{0.1})/D_{0.5} \tag{1}$$

2.4. Color difference analysis of SBP powders

Color difference of different SBP powders was determined by a colorimeter HunterLab LabScan XE (LabScan Co., Ltd., US), working with D65 (day light). CIE color parameters were used in this study: L^*, from black (0) to white (100); a^*, from green (−) to red (+); and b^*, from blue (−) to yellow (+) (Paschoalick, Garcia, Sobral, & Habitante, 2003). The powders color was expressed as difference of color ΔE^*.

$$\Delta E^* = \sqrt{(L^* - L_0)^2 + (a^* - a_0)^2 + (b^* - b_0)^2} \tag{2}$$

where L_0, a_0 and b_0 are L, a and b values of M40 sample as a control sample.

2.5. Test procedure for bulk and tap density

The bulk density ($\times 10^3$ kg/m^3) was determined according to the method applied before (Bai & Li, 2006). Five types of SBP powders were poured into a measuring cylinder. The bulk density value which calculated as the ratio of mass of the powder and the volume was determined by the equation below:

$$\rho_{bulk} = (m - m_0)/V_0 \tag{3}$$

where ρ_{bulk} ($\times 10^3$ kg/m^3) was the bulk density, m (g) was the total weight of the powder and the cylinder, m_0 (g) the weight of the cylinder only, and the V_0 (mL) was the volume of the cylinder.

The tap density ($\times 10^3$ kg/m^3) was determined according to China National Standard GB/T 21354-2008 (2008). Five types of SBP powders (100.0 g) were weighed accurately and poured into 100 mL measuring cylinders. The cylinder was shocked slightly on a thick rubber blanket until the volume of powders no longer reduced. The final volume of reading for value was recorded as V (mL). The tap density was determined by the equation below:

$$\rho_{tap} = M/V \tag{4}$$

2.6. Determination of the angle of repose and slide

The angle of repose (θ) was defined as the maximum angle subtended by the surface of a heap of powder against the plane which supported it (Taser, Altuntas, & Ozgoz, 2005). The angle of repose measurement was undertaken using the following steps. Firstly, a funnel was fixed vertically above a glass petri dish on the experiment table. Then different particle sized SBP powders were continuously poured into the funnel until the powder cone touched the outlet of the funnel. The height (H) and the diameter ($2R$) of the cone were measured after the cone was stable after 2 min. The angle of repose was calculated by the equation below:

$$\theta = \arctan(2R/H) \tag{5}$$

The angle of slide was measured according to the method by Ileleji and Zhou (2008) with minor modification. Ten grams (10.0 g) of different particle sized SBP powders were placed on a glass plane and shaking slightly for uniform distribution. After that, the glass plane was lifted until the SBP powders started to slide. The angle of slide was the angle between the inclined glass plane and horizontal plane. The angle of slide (α) was calculated by the following equation:

$$\alpha = \arcsin(h/L) \tag{6}$$

where the h (cm) was the vertical distance between the top of inclined glass plane and the horizontal plane; the L (cm) was the length of the glass plane.

2.7. Determination of water holding and oil binding capacity

The water binding capacities (WBC) of the SBP powders were determined using the method of Auffret, Ralet, Guillon, Barry, and