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FULL LENGTH ARTICLE

Effects of fluidized bed drying on the quality of soybean kernels

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Abstract The effects of air temperature and velocity on the drying qualities (cracking, bulk density, shrinkage and rehydration) of soybean kernels in fluidized bed dryer were investigated. Drying was carried out at 80, 100, 120 and 140 °C and air velocity of 1.8, 3.1 and 4.5 m/s. Soybean kernels were dehydrated from the initial moisture content of 25% (w.b) to a final moisture content of 10%. The drying evaluation showed that high drying temperature and air velocity resulted in high cracking and low rehydration ratios ($P < 0.05$). However, air velocity had no significant effect on bulk density and shrinkage of soybeans. By increasing the temperature and air velocity over their full ranges, drying time decreased from 380 to 50 min. Cracking, bulk density, degree of shrinkage and rehydration ratio varied from 31.80% to 58.22%, 1101.31 to 1186.39 kg/m^3, 0.730 to 0.787, and 0.583 to 0.873, respectively. Regression equations were established which can be used for the estimation of the quality parameters as a function of the drying variables.

1. Introduction

Soybean is currently one of the most important agricultural food sources in the world and it is high in quality as a source of protein for human and animal diets (Pfeifer et al., 2010; Rafiee et al., 2009). Soybeans are allowed to dry in the field to the optimum harvest moisture range of 13–15% (wet basis) for maximum weight and minimum field loss (USDA, 2008; Sangkram and Noomhorm, 2002). However, in unfavorable weather, soybeans have to be harvested at high moisture (25–33% wet basis) and then dried by artificial drying (Soponronnarit et al., 2001; Stewart et al., 2003). Soybeans to be stored for < 6 months are usually dried to 13% moisture content (wet basis) and 10–11% moisture content for longer storage times of 6–12 months (Stewart et al., 2003; Wiriyaumpaiwong et al., 2003; Li et al., 2002).

Drying is by far the oldest and the most widely used method of preserving foods. During drying, water is removed from a bioproduct, reducing the potential for microbial growth and undesirable chemical reactions, therefore increasing shelf life. It is necessary to dry the product with high quality, minimum cost, energy and time. In fluidized bed drying, drying time is shortened due to intensive heat and mass transfer between drying air and particles being dried and overheating is prevented (Bakal et al., 2011; Dondee et al., 2011; Goksu et al., 2005).

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The literature contains many reports about changes in soybean kernel quality during drying. Soponronnarit et al. (2001) studied strategies for the fluidized bed drying of soybeans at temperatures of 80–120 °C, moisture contents of 31–49% dry basis and air speeds of 2.4 ± 4.1 m/s, finding that cracking increased with drying time, temperature and velocity. Also, Sangkram and Noomhorm (2002) showed that high drying temperature caused high skin cracks of the beans. Dondee et al., 2011 reported that the cracking and breakage of soybean kernels occurred negligible in infrared-fluidized bed dryer, which was lower than 4.4% and 5.3% for cracking and breakage, respectively. Hirunlabh et al. (1992) studied strategies for the batch drying of soybeans at temperatures of 44–75 °C, from moisture contents of 25–11% (d.b.), finding that cracking increased with both drying time and temperature.

Felipe and Barrozo (2003) analyzed the effect of the main process variables (drying air temperature, velocity, air relative humidity, and solids flow rate) on the soybean kernel quality during concurrent moving bed drying. Result showed that a high air relative humidity and a low solid flow rate also assure a better physical quality of kernels, expressed by a high index of non-fissured kernels. Stewart et al. (2003) compared the effect of forced convection drying (FC) and microwave assisted drying (MW) on some unsaturated fatty acids and trypsin inhibitor activity (TIA) in soybeans. They reported that the soybeans dried using FC contained acceptable low levels of TIA, making them adequately processed for food purposes, but suffered greater degrees of fatty acid degradation. Also, soybeans dried using MW retained higher levels of TIA.

Barrozo et al. (2005, 2006) showed that for a Brazilian cultivar of soybean at a temperature of below 45 °C, a low air flow rate and high air humidity are essential to kernel drying. They showed that the air velocity has to be lower than 1.5 m/s. Overhults et al. (1973) studied soybean drying from moisture contents of 25–30% wet basis to 11%, in a thin bed, at drying temperatures of 38–104 °C. At high drying temperatures, the physical surfaces of the soybeans were damaged, with cracks appearing. Gowen et al. (2008) investigated the effect of convective hot-air (160–200 °C), microwave (210–560 W) and combined microwave – hot-air dehydration on dehydration rate, rehydration rate and color of soybeans. They reported that optimal drying occurred for the lowest levels of both microwave and air temperature studied, i.e. 210 W and 160 °C. The effect of the silica gel on characteristic fluidization velocities, mixing mechanisms and fluidization quality of soybean kernels has been studied by Li et al. (2002). Kundu et al. (2001) repotted the effect of the drying air temperature, bed height, feed rate, initial moisture content on drying rate of soybean kernels in fluidized bed dryer, and reported that the drying took place mainly in constant rate and falling rate periods. A two-dimensional spouted bed dryer was investigated to determine the cracking and breakage of soybeans by Wiriyaumpaiwong et al. (2003). They showed that the initial moisture content and inlet air temperature conditions cause cracks in the kernels.

Hence, it is important to determine the optimal combination of drying parameter and dryer configuration that will minimize the loss of kernel quality. Therefore, the aim of this work is to investigate the effect of temperature and air velocity on the soybean quality including rehydration, bulk density, shrinkage and cracking.

2. Materials and methods

2.1. Sample preparation

Kernel quality soybeans were obtained from Gorgan region of Iran. They were stored at a temperature of 4 ± 0.5 °C until the drying process. Soybean samples had an initial moisture content of 25 ± 0.5% wet basis, which was determined by drying the fresh soybean kernels in the hot air oven at 75 °C for 2 days (Stewart et al., 2003). Samples were then dried to around 10% moisture content (wet basis).

2.2. Drying equipment and procedure

The fluidized bed dryer was designed and fabricated in the department of agricultural machinery of Tarbiat Modares University, Tehran. A cylindrical Pyrex column of 90 mm diameter (100 mm outside diameter) and 600 mm height was used as the fluidized bed dryer chamber. A backward-curved blade centrifugal fan driven by a 2.2 kW motor was used to supply hot air into the dryer. The distributor was tightly fixed to the bottom of the column. The distributor plate, 1 mm thick, had 3 mm diameter holes on 6.2 mm triangular pitch. A 24 kW electrical heater was equipped to heat the air. A PID controller was used to control the temperature with an accuracy of 0.1 °C. Airflow rate was controlled using a variable speed unit. Air velocity was measured using a digital anemometer (Extech's Model 45158 Anemometer, USA) with the accuracy of ±0.2 m/s. Before each experiment, the temperature and velocity of the drying air were fixed and measured directly when no sample in the cylindrical chamber. Drying experiments were conducted at 80, 100, 120 and 140 °C and air flow rate of 1.8, 3.1 and 4.5 m/s with three replications in laboratory having ambient conditions of 18 ± 1.5 °C and 34 ± 1.8% relative humidity. After drying, the kernels were cooled for 15 min, and kept in glass jars for future measurements. Analysis of variance (ANOVA) was carried out to study the effect of temperature and air velocity on quality parameters of soybean kernels.

2.3. Cracking

The cracking of soybean kernels was inspected visually by sorting out the cracked kernel with fluorescent light using a 80 g sample. Cracking percentage (Cr) can be calculated using the following equation (Dondee et al., 2011):

$$\mathrm{Cr} = \frac{m_c}{m_s} \times 100 \quad (1)$$

where m_c and m_s are mass of creaked kernels and mass of the sample (kg), respectively.

2.4. Shrinkage and bulk density

Bulk density is the ratio of the mass of sample kernels to its total volume and it was determined by filling a cylinder of known volume (30 mm diameter and 60 mm height) with kernels and weighed in an electronic balance.

$$\rho = \frac{m}{V} \quad (2)$$