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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.

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

where p is the bulk density (kg/m^3), m is the mass (kg) and V is the cylinder volume (m^3).

The degree of shrinkage (S) can be calculated from the bulk density of fresh (ρ_{bf}) and dried soybeans (ρ_{bd}), and from the moisture contents of fresh (X_0) and dried material (X_{dry}) on a dry basis using Eq. (3) (Baysal et al., 2003):

$$S = \frac{\rho_{bf}}{\rho_{bd}}\left(\frac{1 + X_d}{1 + X_f}\right) \quad (3)$$

2.5. Rehydration ratio

Five grams of the dried soybean kernels was added to 60 ml of distilled water, in a 300 ml flask beaker at 25 °C for 2 h. Then, the samples were weighed using a digital balance (GF-600, A & D, Japan) with a precision of 0.01 g. The rehydration ratio of the dried soybeans was then calculated as follows (Nathakaranakule et al., 2010):

$$\mathrm{Rr} = \frac{m_1 - m_d}{m_1} \quad (4)$$

where m_1 is the mass of rehydrated soybean samples (kg) and m_d is the mass of dried soybeans (kg).

3. Results and discussion

3.1. Cracking

Soybean drying by fluidization at high temperatures caused soybeans to crack in V-shaped fissures. The variations in cracking of soybeans with air velocity and temperature are presented in Fig. 1. The cracking of soybeans varied from a minimum of 31.80% to a maximum of 58.22% for the studied range of the independent variables. As depicted in Fig. 1, an increasing trend in the cracking of soybeans was observed with both air velocity and temperature. This damage of soybean kernel is mainly because of high heat and mass transfer rates, from the surface kernel, during the drying process leading to the development of moisture gradient inside each kernel and resulting in cracking at the kernel surface (Dondee et al., 2011; Soponronnarit et al., 2001). Since water movement is limited by water diffusion in the kernels, the temperature of soybean surface increases to more than the air wet bulb temperature as drying proceeds, so that the kernels become brittle at the surface and prone to cracking. Also, increased kernel damage at higher air velocities is due to the combined effects of drying rate and kernel impact against other kernels and wall chamber (Wiriyaumpaiwong et al., 2003; Dondee et al., 2011; Overhults et al., 1973; Hirunlabh et al., 1992).

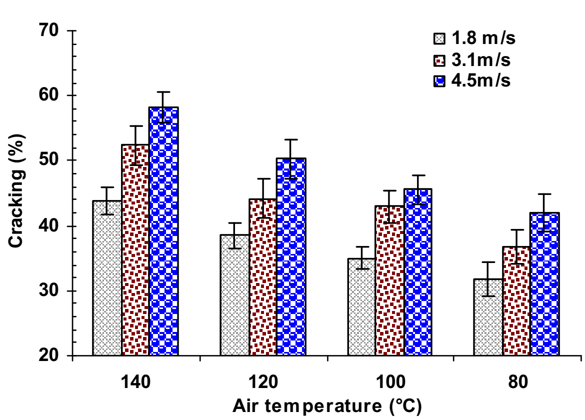

Figure 1 Effect of temperature and air velocity on cracking of soybean kernels.

Soponronnarit et al. (2001) showed that the cracking of soybeans was dependent on both air velocity and temperature in the ranges of 1.5–2.5 m/s and 110–140 °C, respectively, and increased from 40% to 60%. Sangkram and Noomhorm (2002) found that cracking increased from 21.5% to 46.4% with an increase in temperature from 80 to 140 °C. Wiriyaumpaiwong et al. (2003) showed that the cracking of soybean increased from 40% to 80% by increasing air velocity from 15.86 to 20.50 m/s and temperature from 120 to 150 °C during drying process. Also, Sangkram and Noomhorm (2002) showed that one-stage drying at high levels of air temperature (120–140 °C) resulted in more damage (40.5–46.4%) when compared to the two-stage drying. This was due to a rapid drying near the bean surface which caused the outer portion of the beans to shrink before the inner portion had begun to dry, therefore causing physical stress to the beans. Dondee et al. (2011) reported that the cracking of soybean kernels under combined near-infrared radiation and fluidized-bed drying increased with an increase of near-infrared radiation power from 2.9% at 4 kW to 4.4% at 8 kW. This reduction in the cracking of soybean kernels was mainly because the near-infrared radiation energy was absorbed by the moisture inside soybean kernels. Also, it can be attributed to sample surface cooling due to low ambient air temperature (40 °C) which decreases moisture gradient and thermal stress at soybean grain surface; hence the cracking of kernels was reduced. Surprisingly, the cracking of soybean kernels under fluidized-bed drying conditions in the present study was low when compared with fluidized bed drying at the same level of moisture content, reported in previous studies. The differences between the results can be explained by effect the drying method, dryer type, variety characteristics of soybeans and the differences in the levels of the independent variables.

To evaluate the individual effect of independent variables on cracking, analysis of variance (ANOVA) was conducted as reported in Table 1. It can be observed that air velocity and temperature had significant effects ($p < 0.05$) on cracking of soybean kernels. Comparing F-values of the air velocity and temperature showed that the effect of air velocity on cracking was higher (high F-value) than that of temperature (low F-value). Multiple regression analysis showed that there is a linear relationship between cracking percentage and the independent variables of air velocity (u, m/s) and temperature (T, °C) as follows:

$$\mathrm{Cr} = 4.029 + 0.235T + 4.330u \quad R^2 = 0.964 \quad (5)$$

3.2. Shrinkage and bulk density

Analysis of variance (ANOVA) revealed that temperature and temperature × velocity significantly affected soybean bulk density and shrinkage ($P < 0.05$), while air velocity was not a significant factor ($P > 0.05$) during fluidized bed drying (Table 1). Value of bulk density and degree of shrinkage of

Table 1 Analysis of variance results for quality parameters of soybean kernels.

Parameter	Source of variation	Sum of Squares	df	F-value	Sig.
Cracking	T	1023.09	3	52.59	0.000**
	u	830.44	2	64.03	0.000**
	$T \times u$	28.95	6	0.744	0.620*
Bulk density	T	21142.2	3	18.612	0.000**
	u	896.6	2	1.184	0.318*
	$T \times u$	7553.7	6	3.325	0.010*
Shrinkage	T	0.00929	3	18.612	0.000**
	u	0.00039	2	1.184	0.318*
	$T \times u$	0.00332	6	3.325	0.010**
Rehydration	T	0.176	3	131.87	0.000**
	u	0.081	2	90.79	0.000**
	$T \times u$	0.077	6	28.94	0.000**

* Not significant ($p > 0.05$).
** Significant ($p < 0.05$).

Table 2 Bulk density of soybean at different drying conditions.

T (°C)	Air velocity (m/s)		
	1.8	3.1	4.5
140	1101.31 (±21.27)[d]	1091.49 (±8.11)[d]	1123.53 (±12.32)[cd]
120	1111.87 (±30.98)[abc]	1110.15 (±12.81)[ab]	1130.91 (±3.11)[abcd]
100	1116.84 (±20.31)[ab]	1101.86 (±19.29)[ab]	1121.88 (±16.84)[bcd]
80	1148.91 (±19.45)[ab]	1186.39 (±27.85)[a]	1143.51 (±22.74)[abcd]

Table 3 Degree of shrinkage of dried soybean.

T (°C)	Air velocity (m/s)		
	1.8	3.1	4.5
140	0.730 (±0.014)[b]	0.724 (±0.005)[a]	0.745 (±0.008)[be]
120	0.737 (±0.021)[cde]	0.736 (±0.008)[de]	0.750 (±0.002)[bcde]
100	0.741 (±0.013)[de]	0.731 (±0.013)[de]	0.744 (±0.011)[bcd]
80	0.762 (±0.013)[de]	0.787 (±0.018)[e]	0.758 (±0.015)[bcd]

dried soybeans are shown in Tables 2 and 3. It is seen that at each air velocity, bulk density and shrinkage increased with temperature. The decreasing trend of the bulk density and degree of shrinkage with an increase in temperature is in agreement with findings of previous researchers (Baysal et al., 2003; Leeratanarak et al., 2006; Caixeta et al., 2002; Khraisheh et al., 2004; Pimpaporn et al., 2007; Thuwapanichayanan et al., 2011). This is because of the fact that drying time (Fig. 2) at low temperature is higher than that at high temperature (Nathakaranakule et al., 2010). As the temperature and air velocity were increased, drying time significantly reduced (Fig. 3). Working at 140 °C and 4.5 m/s instead of 80 °C and 1.8 m/s, decreases the drying time by 86.8%. Drying time of soybean kernels under fluidized-bed drying in this present study was low when compared with hot-air or fluidized-bed drying, reported by previous studies: 80–450 min (Sangkram and Noomhorm, 2002) and 120–420 min (Boeri and Khatchatourian, 2012). During the drying process, water escapes the cell causing a decrease in tension that the liquid exerts against the cell wall. This decrease in tension causes shrinkage of the material (Hashemi et al., 2009; Janjai et al., 2010). Also, Mayor and Sereno (2004) reported that heating and loss of water cause stresses in the cellular structure of the food and this leads to changes in shape and a decrease in dimensions. Depending on temperature and air velocity, bulk density and degree of shrinkage of dried soybeans ranged from 1101.31 to 1186.39 kg/m^3, and 0.730 to 0.787, respectively. Results shown that significantly different bulk density values of a product can be caused by variation in particle size or dry matter content.

3.3. Rehydration ratio

Rehydration ratio is widely used as a quality index after drying of fruits and vegetables. Food rehydration ratio can provide useful knowledge of the damage that occurs during drying (Aversa et al., 2009). The analysis of variance results (Table 1) clearly indicates the greater effect of temperature (high F-value) than that of air velocity on the rehydration ratio. The effect of air velocity and temperatures on the rehydration ratio of dried soybean samples is illustrated in Fig. 3. The lowest and highest rehydration ratios were 0.583 and 0.873 at 140 °C, 4.5 m/s and 80 °C, 3.1 m/s, respectively. According to Fig. 3, rehydration ratio at high levels of temperature and air velocity improves rehydration due to the effect of temperature on cell wall and tissue (Doymaz and Ismail, 2010). Multiple regression analysis showed that there is a nonlinear relationship between the rehydration ratio (Rr), air velocity (u) and temperature (T) of soybean samples as follows:

$$\mathrm{Rr} = \mathrm{a}u^2 + \mathrm{b}u + c \quad R^2 = 0.998 \tag{6}$$

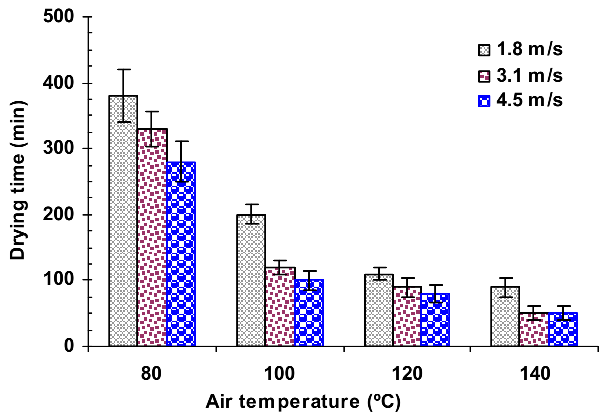

Figure 2 Total drying time of soybean kernels at different temperatures and air velocities.

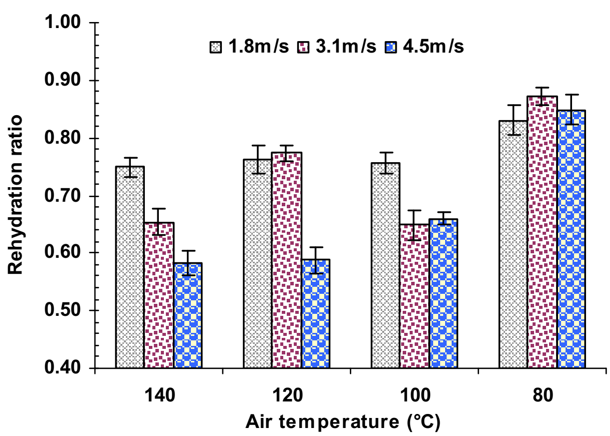

Figure 3 Effect of drying conditions on the rehydration ratio of dried soybean samples.

$$a = -2 \times 10^{-6}T^3 + 0.0006T^2 - 0.692T + 2.4096 \quad R^2 = 0.999 \tag{6-1}$$

$$b = -1 \times 10^{-5}T^3 + 0.00048T^2 - 0.5471T + 20.129 \quad R^2 = 0.997 \tag{6-2}$$

$$c = 2 \times 10^{-5}T^3 - 0.0054T^2 + 0.6178T - 21.957 \quad R^2 = 0.996 \tag{6-3}$$

4. Conclusions

From the experimental results of fluidized bed drying, it could be concluded that the percentage of cracking of soybean kernels (31.80–58.22%) increased with drying temperature, air velocity and drying time. Effect of air temperature on the quality parameters of soybean kernels was more than that of air velocity. The highest rehydration ratio (0.873) was obtained at 80 °C and 3.1 m/s, while increasing drying air temperature also increased it. Besides, increasing the drying air temperature decreased kernels' bulk density (1186.39–1101.31 kg/m3) and degree of shrinkage (0.787–0.730), while air velocity had no significant effect on shrinkage or bulk density.

References

Aversa, M., Curcio, S., Calabro, V., Iorio, G., 2009. Experimental evaluation of quality parameters during drying of carrot samples. Food Bioprocess Technology. http://dx.doi.org/10.1007/s11947-009-0280-1.

Bakal, S.B., Sharma, P.G., Sonawan, S.P., Verma, R.C., 2011. Kinetics of potato drying using fluidized bed dryer. Journal of Food Science Technology. http://dx.doi.org/10.1007/s13197-011-0328-x.

Barrozo, M.A.S., Felipe, C.A.S., Lacerda, A.F., Lisboa, M.H., 2005. Analysis of soybean seed quality related to drying in parallel flow sliding bed. Seed Science Technology 33, 675–685.

Barrozo, M.A.S., Felipe, C.A.S., Sartori, D.J.M., Freire, J.T., 2006. Quality of soybean seeds undergoing moving bed drying: counter current and cross current flows. Drying Technology 24, 415–422.

Baysal, T., Icier, F., Ersus, S., Yıldız, H., 2003. Effects of microwave and infrared drying on the quality of carrot and garlic. European Food Research and Technology 218, 68–73.

Boeri, C.N., Khatchatourian, O., 2012. Numerical simulation to describe the soybean Glycine max (L.) drying process: Influence of air velocity, temperature and initial moisture content. International Journal of Mechanical Engineering 2 (2), 30–41.

Caixeta, A.T., Moreira, R., astell-Perez, M.E., 2002. Impingement drying of potato chips. Journal of Food Process Engineering 25, 63–90.

Dondee, S., Meeso, N., Soponronnarit, S., Siriamornpun, S., 2011. Reducing cracking and breakage of soybean grains under combined near-infrared radiation and fluidized-bed drying. Journal of Food Engineering 104, 6–13.

Doymaz, I., Ismail, O., 2010. Drying and rehydration behaviors of green bell peppers. Food Science Biotechnology 19 (6), 1449–1455.

Felipe, C.A.S., Barrozo, M.A.S., 2003. Drying of soybean seeds in concurrent moving bed: heat and mass transfer and quality analysis. Drying Technology 21 (3), 439–456.

Goksu, E.L., Sumnu, G., Esin, A., 2005. Effect of microwave on fluidized bed drying of macaroni beads. Journal of Food Engineering 66, 463–468.

Gowen, A.A., Abu-Ghannam, A., Frias, J., Oliveira, J., 2008. Modeling dehydration and rehydration of cooked soybeans subjected to combined microwave – hot-air drying. Innovative Food Science and Emerging Technologies 9, 129–137.

Hashemi, G., Mowla, D., Kazemeini, M., 2009. Moisture diffusivity and shrinkage of broad beans during bulk drying in an inert medium fluidized bed dryer assisted by dielectric heating. Journal of Food Engineering 92, 331–338.

Hirunlabh, J., Tirawanithakul, S., Soponronnarit, S., 1992. Strategies for Drying soybean: batch process. Songklanakarin. Journal of Science Technology 14, 33–46.

Janjai, S., Mahayothee, B., Lamlert, N., Bala, B.K., Precoppe, M., Nagle, M., Muller, J., 2010. Diffusivity, shrinkage and simulated drying of litchi fruit (*Litchi Chinensis Sonn.*). Journal of Food Engineering 96, 214–221.

Khraisheh, M.A.M., McMinn, W.A.M., Magee, T.R.A., 2004. Quality and structural changes in starchy foods during microwave and convective drying. Food Research International 37, 497–503.

Kundu, K.M., Datta, A.B., Chatterjee, P.K., 2001. Drying of oil seeds. Drying Technology 19 (2), 343–358.

Leeratanarak, N., Devahastin, S., Chiewchan, N., 2006. Drying kinetics and quality of potato chips undergoing different drying techniques. Journal of Food Engineering 77, 635–643.

Li, Z., Kobayashi, N., Nishimura, A., Hasatani, M., 2002. Sorption drying of soybean seeds with silica gel. I. hydrodinamics of a fluidization bed dryer. Drying Technology 20 (6), 1193–1213.

Mayor, L., Sereno, A.M., 2004. Modeling shrinkage during convective drying of food material: a review. Journal of Food Engineering 18, 373–386.

Nathakaranakule, A., Jaiboon, P., Soponronnarit, S., 2010. Far-infrared radiation assisted drying of longan fruit. Journal of Food Engineering 100, 662–668.

Overhults, D.G., White, G.M., Hamilton, H.E., Ross, I.J., 1973. Drying soybean with heated air. Transactions of the American Society of Agricultural Engineers 16, 112–113.

Pfeifer, A.A., Murata, V.V., Barrozo, M.A.S., 2010. Modelling of soybean seed drying in concurrent sliding bed dryers: Effect of the number of stages on the seed quality and drying performance. Biosystems Engineering 107, 341–348.

Pimpaporn, P., Devahastin, S., Chiewchan, N., 2007. Effects of combined pretreatments on drying kinetics and quality of potato chips undergoing low-pressure superheated steam drying. Journal of Food Engineering 81, 318–329.

Rafiee, S., Keyhani, A., Sharifi, M., Jafari, A., Mobli, H., Tabatabaeefar, A., 2009. Thin layer drying properties of soybean (Viliamz cultivar). Journal of Agricultural Science and Technology 11, 289–300.

Sangkram, U., Noomhorm, A., 2002. The effect of drying and storage of soybean on the quality of bean, oil, and lecithin production. Drying Technology 20 (10), 2041–2054.

Soponronnarit, S., Swasdisevi, T., Wetchacama, S., Wutiwiwatchai, W., 2001. Fluidised bed drying of soybeans. Journal of Stored Products Research 37, 133–151.

Stewart, O.J., Raghavan, G.S.V., Orsat, V., Golden, K.D., 2003. The effect of drying on unsaturated fatty acids and trypsin inhibitor activity in soybean. Process Biochemistry 39, 483–489.

Thuwapanichayanan, R., Prachayawarakorn, S., Kunwisawa, J., Soponronnarit, S., 2011. Determination of effective moisture diffusivity and assessment of quality attributes of banana slices during drying. LWT – Food Science and Technology 44, 1502–1510.

USDA. 2008. Soybean drying and storage. Iowa State University of Science and Technology, Ames, Iowa, Pm-1636.

Wiriyaumpaiwong, S., Soponronnarit, S., Prachayawarakorn, S., 2003. Soybean drying by two-dimensional spouted drying. Drying Technology 21 (9), 1735–1757.